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Semi-Popular Articles

Technical Literature Review

Utilization Abstracts

By the Editor

The Water-Soluble Gums—*Their Botany, Sources and Utilization*[1]

Arabic, tragacanth, ghatti, karaya and other commercially valuable gums are exudations of a variety of trees and shrubs in many parts of the world. Their hydrophilic and other properties render them useful in the adhesives, beverage, cosmetic, paint, papermaking, pharmaceutical, textile and other industries.

C. L. MANTELL
Consulting Chemical Engineer, New York

Terminology

The term "water-soluble gums" embraces a group of substances, all of which are derived from plants, either directly or indirectly, the property of which to form viscous adhesives, jellies or pastes by absorption of or dispersion in water has earned a place for them in the arts and industries. The term, however, is a misnomer, for the substances are not soluble in the strictly scientific sense, as are salt, sugar and other crystallizable materials. Gums are not crystalloids, but colloids, and as such are strictly amorphous and do not have melting point, freezing point or boiling point characteristics. The designation "water-soluble" serves to distinguish true gums, in a technical sense, from the many other substances to which the term "gum" is also commonly applied but which are not water-soluble and which differ from true gums also in other important respects. These other substances are gum damar, gum copal, gum congo, gum kauri and Manila gum, all of which are resinous, non-water-soluble exudations from plants. In a somewhat related manner the so-called gum-resins, which are mixtures of hydrophilic and hydrophobic constituents, include gum benzoin, gambier, catachouc, gamboge, guaiac, kino, myrrh, storax and the balsams of Peru and Tolu. Addition of dragon's blood completes this listing of commercially important gum-resins which, although designated "gums" in commerce, are not hydrophilic but are closely related to the resins.

Physical Properties

In addition to being colloidally soluble, or dispersible in water, gums are insoluble in drying oils and organic solvents. On heating they decompose completely without melting, usually showing charing. In contradistinction, natural resins are insoluble in water, but more or less soluble in organic solvents and vegetable oils. When heated, resins melt with distillation of volatile oils as the temperature is increased. They do not show a carbonizing point, nor do they produce coke when destructively distilled. Gums are totally unrelated to resins—physically, chemically or application-wise.

True gums are roughly divisible into three classes: *a*) truly soluble gums, typified by gum arabic, which form trans-

[1] This article is abstracted, with permission of the copyright owners, from the book "The Water-Soluble Gums", 279 pages, by the same author and published in 1947 by Reinhold Publishing Corp. That volume contains much chemical and technological information concerning gums which has been omitted from this condensed version of the book.

parent colloidal solutions in water; *b*) so-called insoluble gums, represented by tragacanth, which absorb the aqueous medium, swell into a jelly and finally, on addition of sufficient water, break down into a very thick transparent solution; *c*) half-soluble gums, represented by so-called "Persian insoluble gum", which are intermediate in their properties, dispersing in water to form a swollen jelly and then passing into solution on addition of more water.

In addition to these differences in solubility, the various gums differ from one another in a number of other physical qualities, and these differences render them suitable for different industrial uses, as explained later. Each of the gums finds specific application in industrial usage where the others neither replace nor supplement it; each has earned its place over thousands of years or in a short span of time after it reached a stage of commercial production.

Chemical Properties

Gums, in general, are complex associations of celluloses, starches, sugars, the reaction and oxidation products of these materials and the acids and salts of compounds consisting only of carbon, hydrogen and oxygen. They are thus closely related chemically to the carbohydrates. In addition to the three mentioned elements, they contain more or less mineral matter, chiefly calcium, magnesium and potassium. Nitrogen is in many cases a component but not always. In this respect gums differ from proteins, of which nitrogen is an essential component.

On hydrolysis gums yield various products which betray their chemical makeup, as shown in Table 1.

Commercial Sources

Commercial gums are obtained by tapping, or by collecting them from the surface of, certain trees and shrubs; by extraction from marine plant life; by milling from some seeds and extraction from others; by thermal treatment of starches from kernels or root crops; by chemical processing of cellulose from tree trunks and the cotton plant; as well as by separation of animal by-products and purification procedures.

The water-soluble gums enter commerce from many portions of the world, mostly from agricultural and non-industrialized areas. In general, they originate in the following parts of the African continent: the Sudan (Sudan or Kordofan gum); the forest of the Blue Nile (talh or talha gum); the French Colony of Senegal (Senegal gum); Northern Nigeria (gum arabic); Morocco ("Morocco", "Mogadore", "Brown Barbary" gum); Tripoli (gum arabic); Tunisia (gum arabic); Tanganyika (gum arabic); Southwest Africa (acacia); Cape Colony, Orange River Colony, Somaliland and Abyssinia (Aden and East Indian gum); in portions of Asia, as India and adjacent countries (ghatti and karaya gum); in Asia Minor, Kurdistan and Iran (tragacanth); in Australia (wattle gum); in South America where usage is mostly local; and to a small extent in Europe (cherry gum).

The seaweed colloids—agar, Irish moss and the alginates—are derived from marine products gathered off the coast of Japan, the east and west coasts of the United States, the marine areas of the British Isles and Europe, and the shores of the Atlantic and Pacific Oceans.

The processed carbohydrates, *e.g.*, dextrins and British gums, are derived from American starches such as corn and potato, as well as tapioca from the Netherlands Indies. The hemicelluloses are from seeds of trees and other plants from Europe, Iran, the Argentine and the United States. Gelatin is ordinarily derived from animal sources in the United States. Synthetic competitors of the gums, such as the processed celluloses, are from native or Canadian wood pulp or American cotton linters.

Gum Arabic

The dried gummy exudations from the trunks and branches of many species of *Acacia* have been collected since Biblical times and constitute the true gum arabic of commerce. The term has been applied also in a very broad general sense to almost any gum, regardless of its botanical source, which disperses in water to form a mucilage. True arabic, however, is yielded only by species of *Acacia*. Some 400 of them are widely distributed over very extensive areas of arid northern Africa, from Dakar and Senegal on the west Coast across the continent to the Red Sea; throughout Arabia; and in portions of Iran, India and Australia. They are found also in the semi-arid areas of the American Southwest, in Mexico and in Central America. Other sections of the tropics throughout the world also have their representatives of the genus. Only a few of these many species, however, are commercially important.

The term "gum arabic" has become generic, although it was originally a locality designation. As such it has been superseded by other names indicating areas in which the exudations are collected. These are "Sudan gum", "Kordofan gum", "Khartoum gum", "Turkey gum", "Senaar gum", "Geddaref gum", "Jeddah gum" and others. Although not so broadly used and often employed only locally, there are also "Gedda gum", "Sennari gum", "Turic gum" and "Gehzirah gum". In general the different varieties of exudations from acacia trees are collected in the Sudan of Africa, Upper Egypt, Ethiopia, Somaliland and adjacent areas. The most important of them are grouped under two general categories, namely, "Sudan" or "Kordofan", and "Senegal".

TABLE 1.

COMPOSITION AND HYDROLYSIS PRODUCTS OF NATURAL GUMS

Gum	*Apparent Chemical Composition*	*Hydrolysis Products*
Agar	Sulfuric ester of a linear galactan	....
Algin	Polyuronic acid	Cellulose, uronic acid, mannuronic acid
Arabic	Metal salt of a complex organic acid	Mixture of arabinose, galactose, aldobionic acid, galacturonic acid
British gum	Modified carbohydrate	....
Dextrin	Modified carbohydrate	....
Flaxseed	Heterogeneous polysaccharide	Aldobionic acid, *d*-galacturonic acid, *l*-rhamnose
Ghatti	Calcium salt of polysaccharide acid	*l*-arabinose, barium salt of aldobionic acid
Guar	Complex carbohydrate, galactose, mannose	....
Iceland moss	Cellulose, simple sugars	*d*-glucuronic acid
Irish moss	Calcium salt of sulfuric ester of saccharide	Ethereal sulfates (glucose)
Karaya	Galactan, gelose	....
Locust bean	Carbohydrate, mannose, galactose	Caronbinose (mannose), galactose
Methyl cellulose	Synthetic cellulose ether	....
Psyllium seed	Mixture of polyuronides	Arabinose, *d*-glucose, *d*-xylose, aldobionic acid
Quince seed	Cellulose, arabinose, xylose	Arabinose, mixture of aldobionic acids, cellulose
Tragacanth	Calcium salt of complex organic nature	Glucuronic acid, arabinose

Designations

Gums are known by a great variety of names in different parts of the world. These designations are tabulated in Table 2 wherein the local name or trade variant is in the first column, the geographical place of origin in the second column, the botanical source in the third, and the present day classification, as used in this paper, in the last column.

TABLE 2.

DESIGNATIONS AND SOURCES (GEOGRAPHICAL AND BOTANICAL) OF COMMERCIAL GUMS

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
A			
Abyssinia	Abyssinia	*Acacia*	Arabic
Acacia	Africa, Near East	*Acacia*	Arabic
Aden	Africa	*Acacia*	Arabic
Agar	Continental and Japanese Sea Coasts	*Gelidium, Gracilaria*	Agar
Aleppo	Near East	*Astragalus*	Tragacanth
Algin	British Isles, Europe, United States, Nova Scotia	*Laminaria, Macrocystis*	Alginate
Angelique	South America	*Dicorynia*	Karaya substitute
Angico	South America	*Piptadenia*	Arabic substitute
Anogeissus	India	*Anogeissus*	Ghatti
Arabic	Africa, Near East	*Acacia*	Arabic
Arrehbor	Iran (Persia)	*Astragalus*	Tragacanth
Astragalus	Iran, Asia Minor, Armenia, Kurdistan, Palestine, Irak, British India, Russia, Turkey	*Astragalus*	Tragacanth
Australian black wattle gum	Australia	*Acacia*	Arabic
B			
Babool	India	*Acacia*	Arabic
Balsam (resin)	Canada, United States	*Abies*	Canadian balsam
Barbary, brown	Sudan, Africa	*Acacia*	Arabic
Bar Kanten	Japan	*Gelidium*	Agar
Basra	Iran (Persia), Near East	*Astragalus*	Tragacanth
Bassora	Iran (Persia)	*Sterculia*	Karaya
Beira	Argentina	*Caesalpinia*	Karaya substitute
Berbera	Senegal, Africa	*Acacia*	Arabic
Blanche gomme	Sudan, Africa	*Acacia*	Arabic
Blonde gomme	Sudan, Africa	*Acacia*	Arabic
Blonde psyllium seeds	Mediterranean area	*Plantago*	Psyllium
Brea	Argentina	*Caesalpinia*	Karaya substitute
Broadleaf kelp	Europe, United States	*Laminaria*	Alginate
Bushire	Iran (Persia)	*Astragalus*	Tragacanth
C			
Cactus	United States, Mexico, Central and South America	*Opuntia, Carnegeia*	Tragacanth substitute
Canada balsam (resin)	Canada, United States	*Abies*	Canadian balsam
Cape	Union of South Africa	*Acacia*	Arabic
Carmania	Syria	*Prunus*	Ghatti substitute
Carob	South Europe, North Africa, Mediterranean area	*Ceratonia*	Locust bean
Carob seed	South Europe, North Africa, Mediterranean area	*Ceratonia*	Locust bean
Carrageen	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss
Carragheen	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Carrageenin	British Isles, New England, Europe, Nova Scotia	*Chondrus*	Irish moss
Cashew	India	*Anacardium*	Arabic substitute
Catechu	India	*Acacia*	Arabic
Cedar	Central America, West Indies	*Cedrela*	Cedar
Cedro	Central America, West Indies	*Cedrela*	Cedar
Cherry	Europe, United States	*Prunus*	Cherry
Chinese isinglass	Japan, China	*Gelidium*	Agar
Chironji	India	*Buchanania*	Karaya
Chitira	Persia	*Astragalus*	Tragacanth
Chittagong	India	Indefinite	Indian
Chondrus	British Isles, North Europe, New England, Nova Scotia	*Chondrus*	Irish moss
Cutch gum	India	*Acacia*	Arabic
Cydonium	Near East, Asia, Europe, South Africa, United States	*Cydonia*	Quince seed
D			
Date gum	Africa	*Phoenix*	Date
Dhak	India	Indefinite	Indian
E			
East India gum	India, (East Indies)	*Acacia*	Arabic
East Indian gum	Iran (Persia)	*Acacia*	Arabic
Elephant	India	Indefinite	Indian
F			
Flea seed	Mediterranean area	*Plantago*	Psyllium
Fleawort	Mediterranean area	*Plantago*	Psyllium
G			
Gatto	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Gavan	Iran (Persia)	*Astragalus*	Tragacanth
Gedda	Africa	*Acacia*	Arabic
Geddaref	Egypt	*Acacia*	Arabic
Gehzirah	Africa	*Acacia*	Arabic
Ghati	India, Ceylon	*Anogeissus*	Ghatti
Ghatti	India, Ceylon	*Anogeissus*	Ghatti
Goma de Cedro	Central America, West Indies	*Cedrela*	Cedar gum
Goma de Guanacaste	Central America, West Indies	*Enterolobium*	Arabic substitute
Gomme blanche	Sudan, Africa	*Acacia*	Arabic
Gomme blonde	Sudan, Africa	*Acacia*	Arabic
Gomme de Galam	Senegal, Africa	*Acacia*	Arabic
Gomme de Podor	Senegal, Africa	*Acacia*	Arabic
Gomme de Tombouctou	Senegal, Africa	*Acacia*	Arabic
Gomme du bas du fleuve	Senegal, Africa	*Acacia*	Arabic
Gomme du haut de fleuve	Senegal, Africa	*Acacia*	Arabic
Gomme fabrique	Senegal, Africa	*Acacia*	Arabic
Gomme friable	Senegal, Africa	*Acacia*	Arabic
Guamacho	South America	Cactus	Tragacanth substitute
Guar	India, United States	*Cyamopsis*	Guar
H			
Halusia	Iran (Persia)	*Astragalus*	Tragacanth
Hashab geneina	Egypt	*Acacia*	Arabic
Hashab wady	Africa	*Acacia*	Arabic
Hevo	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Hindu tragacanth	India	*Sterculia*	Karaya
Horsetail kelp	Europe, United States	*Laminaria*	Alginate

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
I			
Iceland moss	Iceland, Sweden, Norway	*Cetraria*	Iceland moss
India gum	India	*Sterculia*	Karaya
Indian gum	India, Ceylon	*Anogeissus*	Ghatti
Indian tragacanth	India	*Sterculia*	Karaya
Irish moss	British Isles, Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Isabghol	Mediterranean area	*Plantago*	Psyllium
Isinglass	Continental sea coasts	*Gelidium, Gracilaria*	Agar
J			
Jandagum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Japanese gelatin	Japan	Seaweed	Agar
Japanese isinglass	Japan	*Gelidium, Gracilaria*	Agar
Jeddah	Morocco	*Acacia*	Arabic
K			
Kadaya	India	*Sterculia*	Karaya
Kanten	Continental sea coasts	*Gelidium, Gracilaria*	Agar
Karai	Iran (Persia)	*Astragalus*	Tragacanth
Karaya	India	*Sterculia*	Karaya
Katad	Iran (Persia)	*Astragalus*	Tragacanth
Kathira	Iran (Persia)	*Astragalus*	Tragacanth
Katilo	India	*Sterculia*	Karaya
Katira	Iran (Persia)	*Astragalus*	Tragacanth
Katira-i-hindi	Iran (Persia)	*Sterculia*	Karaya
Katya	Iran (Persia)	*Astragalus*	Tragacanth
Katyra	Iran (Persia)	*Astragalus*	Tragacanth
Keltex	United States	*Laminaria*	Alginate
Kettira	Iran (Persia)	*Astragalus*	Tragacanth
Khartoum	Africa	*Acacia*	Arabic
Killeen	British Isles, Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Kino	India	*Pterocarpus*	Indian gum
Kobe	Japan	*Gelidium*	Agar
Kordofan	Sudan, Africa	*Acacia*	Arabic
Kullo	India	*Sterculia*	Karaya
Kuteera	Asia, Iran (Persia), India	*Sterculia*	Karaya
Kutera	Iran (Persia)	*Astragalus*	Tragacanth
L			
Lakoe	Africa, South Europe, Mediternean area	*Ceratonia*	Locust bean
Locust bean	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Locust kernel	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust kernel
Lupogum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Luposol	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
M			
Mahua	India	*Bassia*	Indian gum
Mangrove	North and South America	*Rhizophora*	Ghatti substitute
"Marrons et bois"	Africa	*Acacia*	Arabic
Mesquite	United States, Mexico, South America	*Prosopis*	Arabic substitute
Mimosa	West Indies, South America	*Mimosa*	Tragacanth substitute

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Mogador	Africa	*Acacia*	Arabic
Moringa	India	*Moringa*	Karaya substitute
Morocco	Africa	*Acacia*	Arabic
O			
Ondurman	Egypt	*Acacia*	Arabic
P			
Peach	United States	*Prunus*	Peach gum
Pearl moss	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Persian tragacanth	Iran (Persia)	*Astragalus*	Tragacanth
Pharmagel	United States	Protein	Gelatin
Pigwrack	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Plantago	Mediterranean area	*Plantago*	Psyllium
Plum tree gum	India	*Prunus*	East Indian gum
R			
Ritha	East Indies	*Sapindus*	Ghatti substitute
Rocksalt moss	Europe, United States, Nova Scotia	*Chondrus*	Irish moss
Rubigum	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
S			
Seaweed isinglass	Japan	*Gelidium*	Agar
Saghalien	Japan	*Gelidium*	Agar
Salabreida	Senegal, Africa	*Acacia*	Arabic
Semla	India	*Sterculia*	Karaya
Senaar	Central America	*Acacia*	Arabic
Senegal	Africa	*Acacia*	Arabic
Sennaar	Africa	*Acacia*	Arabic
Shinshu	Japan	*Gelidium*	Agar
Shiraz	Iran (Persia)	*Anogeissus*	Ghatti
Smyrna tragacanth	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
Siris	India	*Albizzia*	Arabic substitute
Soap-nut tree gum	East Indies	*Sapindus*	Ghatti substitute
Sonora	United States, North and South America	*Prosopis*	Arabic substitute
Sterculia	India	*Sterculia*	Karaya
St. John's bread	Africa, Mediterranean area, Europe	*Ceratonia*	Locust bean
Suakim	Africa	*Acacia*	Arabic
Sudan	Africa	*Acacia*	Arabic
Suleimanaya	Iran (Persia), Irak	*Astragalus*	Tragacanth
Somaliland	Somaliland	*Acacia*	Arabic
Sunt	Arabia, Africa	*Acacia*	Arabic
Swine's bread	South Europe, Africa, Mediterranean area	*Ceratonia*	Locust bean
Syrian	Syria	*Astragalus*	Tragacanth
Syrian tragacanth	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
T			
Talba	Sudan, Africa	*Acacia*	Arabic
Talca	Sudan, Africa	*Acacia*	Arabic
Talh	Africa	*Acacia*	Arabic
Talha	Africa	*Acacia*	Arabic
Tengusa	Japan	*Gelidium*	Agar
Terminalia	India	Indefinite	Indian
Thus gum (resin)	United States	*Pinus*	Rosin
Tragacanth	Iran (Persia), Turkey, Russia, Irak, Palestine, British India, Syria	*Astragalus*	Tragacanth

Name	*Place of Origin*	*Botanical Source*	*Present Day Classification*
Tragon	Africa, Mediterranean area, South Europe	*Ceratonia*	Locust bean
Tragasol	Africa, Mediterranean area, South Europe	*Ceratonia*	Locust bean
Tripoli	Africa	*Acacia*	Arabic
Tunis	Africa	*Acacia*	Arabic
Turic	Africa	*Acacia*	Arabic
Turkey gum	Near East	*Acacia*	Arabic
V			
Vegetable isinglass	Japan	*Gelidium*	Agar
W			
Wattle	India, Australia, Africa, New South Wales	*Acacia*	Arabic
White gum (gomme blanche)	Africa	*Acacia*	Arabic
White leaf gum	Kurdistan, Iran (Persia), Irak	*Astragalus*	Tragacanth
Y			
Yokohama	Japan	*Gelidium*	Agar

Sudan or Kordofan Gum. In the Anglo-Egyptian Sudan and French Senegal areas of Africa alone there are about 25 species of *Acacia*, and of these, *A. Senegal* (L.) Willd., a tree of small size, is by far the most important. There are extensive forests of it in the region of Kordofan which is west of Khartoum in the Anglo-Egyptian Sudan, and it is abundant also between the White Nile and the Blue Nile. In the Sudan Area the tree is often called "hashab", which term the Egyptians and Arabs apply also to the gum.

Commercial production of the gum in this semi-arid country is limited necessarily to those districts which are not too far from sources of water. The gum gatherers must carry all their provisions of food and water, and this limits their collecting to areas which are only a few days journey from depots for replenishment of these supplies. The gum is gathered only in the hottest and driest season because in other seasons the trees are actively growing with sufficient moisture and do not produce gum. The best yields result when an unusually hot dry season follows one of excessive rainfall.

Gum collecting is not an all year vocation for the natives but rather a source of additional income when farming is at a standstill. Although the dry season normally begins in the latter part of September or in October, and the trees may be tapped any time after the first of November, gum gathering is postponed until after the crops have been harvested. The gatherers, therefore, are active only after January or February. The men leave their native villages, carrying their food and water supply, with a spear for defense against native animals or as a hunting implement. Their only gum-gathering tool is a small hatchet with a long handle, and a native woven basket to serve as a container of the collected gum. The collectors cut the trees in not too deep a fashion and then peel a strip of bark an inch or two in width and two to three feet long. Care is taken not to injure the inner bark. The stripping operation is not sufficient to harm the tree, and in time under favorable conditions the wound heals. It appears that the gum is formed through a combination of evaporation of the sap and attack on the plant tissues by bacteria. The gum exudes and forms in drops, or tears, which grow to large size

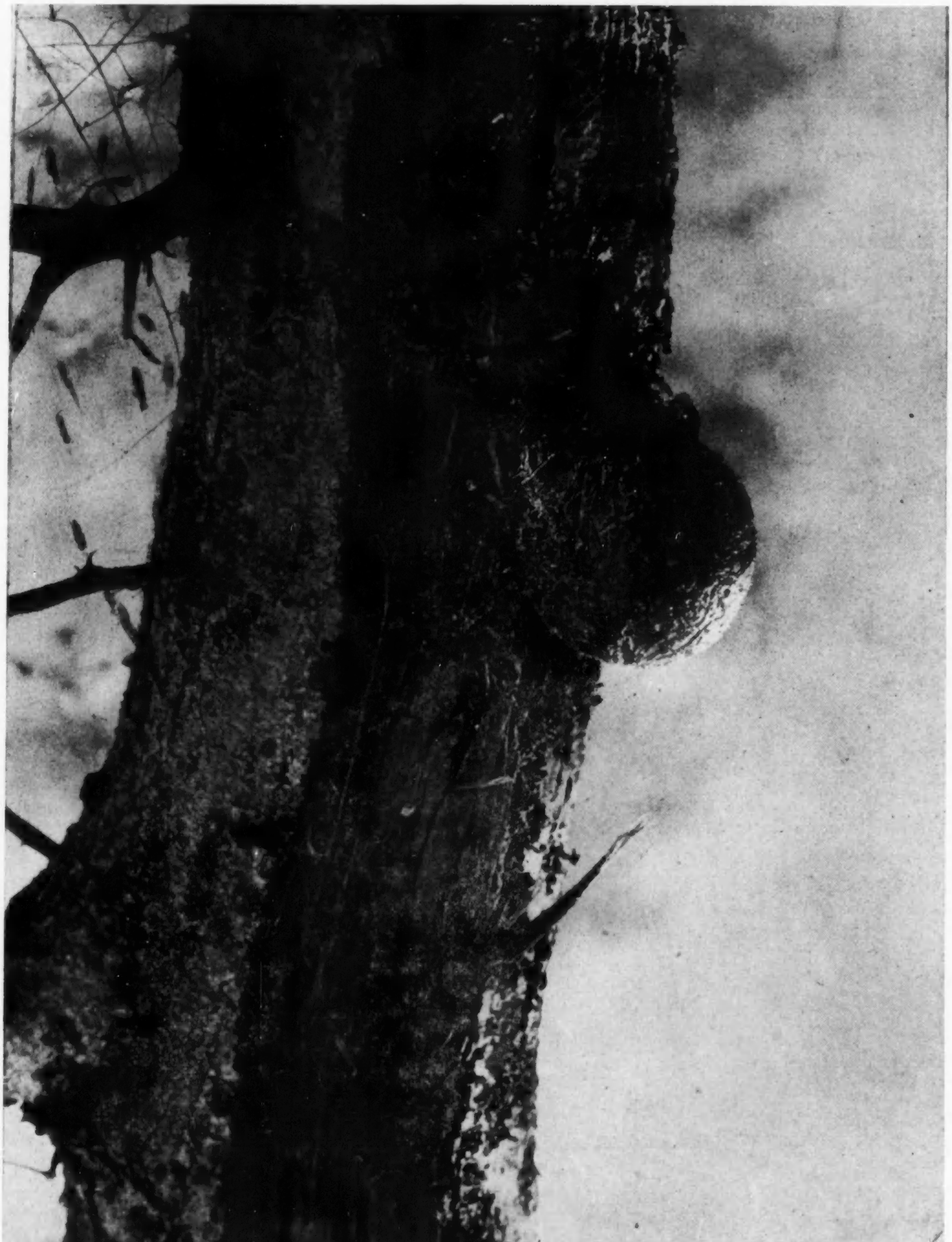

FIG. 1. Exudation of gum arabic at a point of tapping. Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

only after a season of heavy rains which induce the trees to become full of sap and to develop vigorous young growth. When first formed, the tears are soft, the outside being skin-like; but if they are allowed to remain in place for several weeks, the entire mass becomes firm and hard as a result of evaporation from the surface and diffusion of aqueous portions from within the tear to its outside.

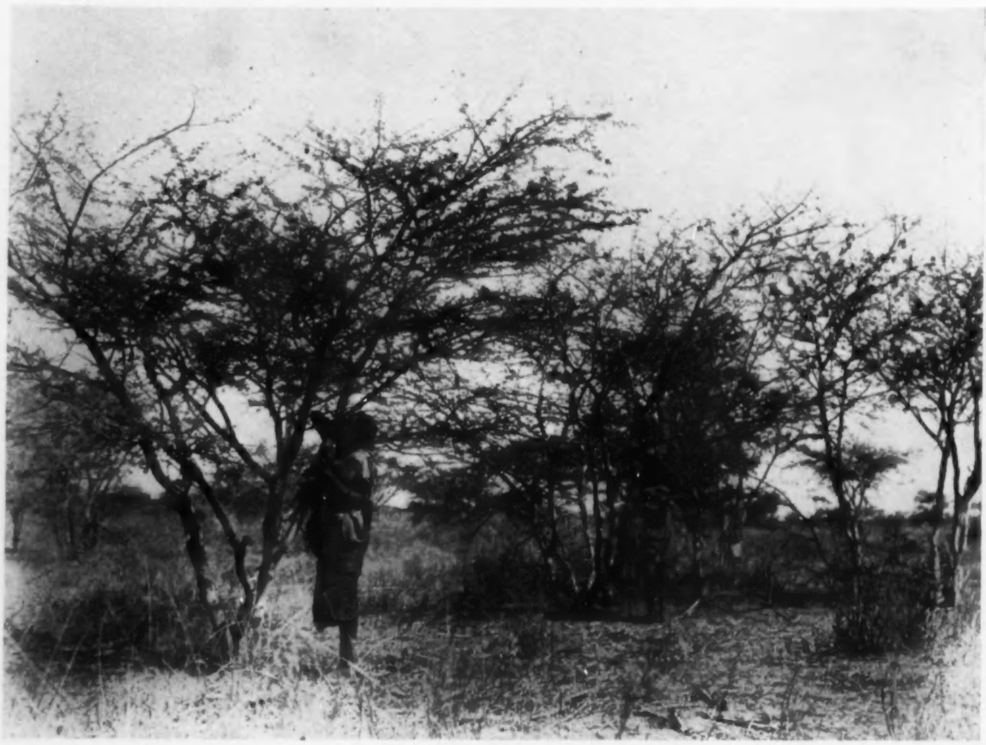

FIG. 2. Gum-arabic garden near Tairara, Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

The gum collectors return with their produce to the villages and sell or barter their gatherings to local traders or representatives of district gatherers. When sufficient stocks are collected, the gum is transported by boat or caravan to wholesale markets, of which Khartoum is typical. Here the gum is graded on the basis of superficial appearance, and in the light of centuries of experience the best grade is reputed to be that of tears which are transparent or nearly so, with only a faint departure from white.

The gum is spread in the sun in thin layers to bleach. The best area for this purpose, according to the natives, is the low sandy shore of the Nile. The drying out in the sun is at a faster rate than the moisture can diffuse from the inside of the tears, so that with expansion and contraction after drying, the tears are filled with innumerable minute cracks. These cause the gum to assume an opaque appearance and a greater degree of whiteness, characters that are typical of good commercial grades. It is unfortunate, however, that these features do not give any indication of the factors to be considered in the use of the gum, namely, color of solution, viscosity, clarity and freedom from insolubles. Cheaper grades are yellowish to red.

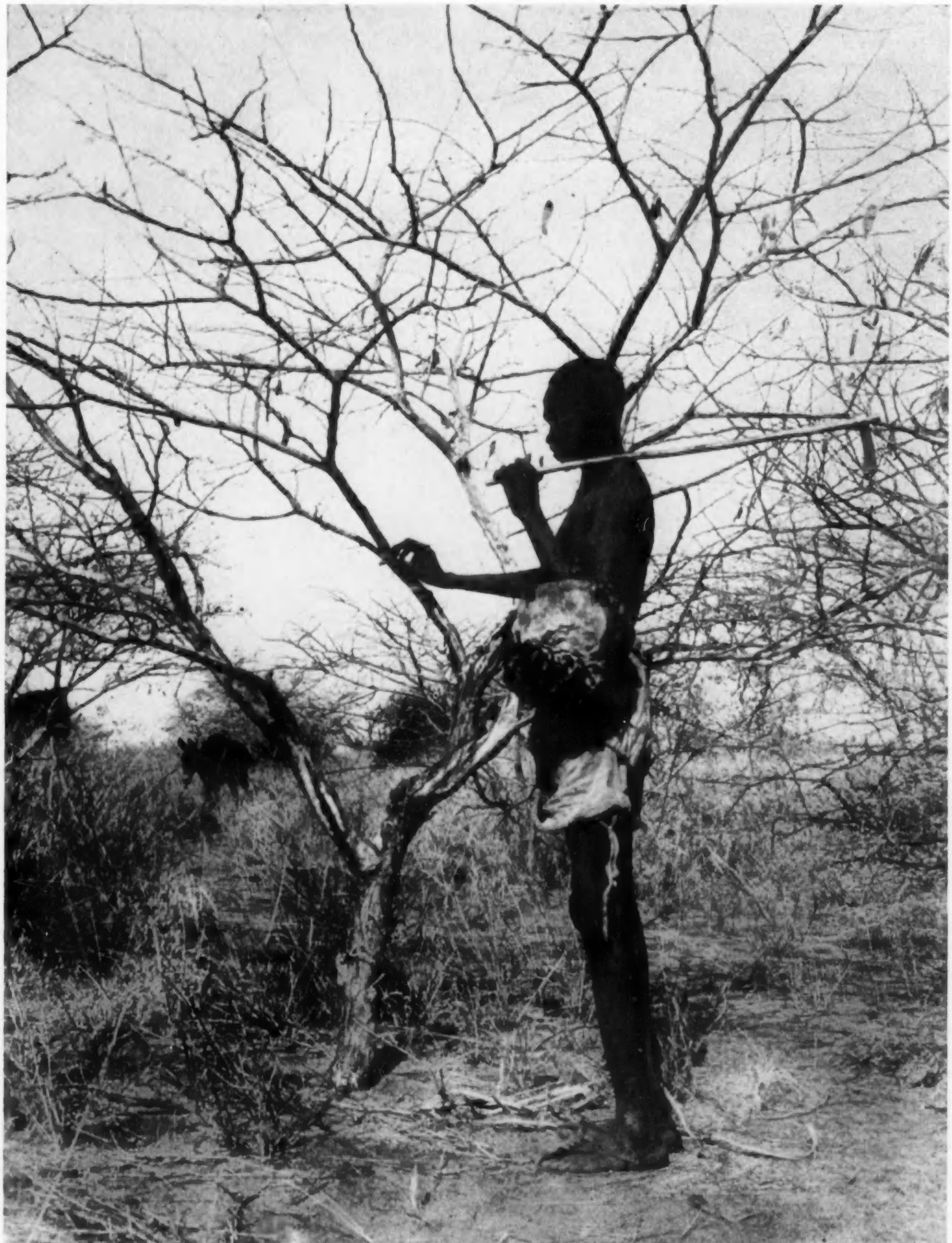

FIG. 3. A native gum-arabic collector. Kordofan, Sudan, Africa. (*Courtesy the Philadelphia Commercial Museum*).

Gum arabic in the restricted geographical sense is the material exported chiefly to Europe from Arabia, most of the trade being handled in the port of Aden. Only a very small portion of the gum, however, is collected in Arabia. For two or three thousand years natives have gathered the gum from wild trees in those parts of Africa adjacent or accessible to the southern end of the Red Sea. The more important traders who collected from the natives were along the Arabian coast, and the gum received its name from them, for it was these arabs who exported the material to Europe. There are indications that caravans carried the gum to North Egypt from Aden as early as the seventeenth century before Christ. The bulk of the material in earlier times was collected, as it is today, in the Sudan, and has long been known as "Sudan" or "Kordofan" gum.

In addition to the wild tree scattered over great areas there are also privately owned cultivated gardens of *A. Senegal* in Kordofan Province. Here the trees are systematically tapped and the gum collected in an orderly manner by organized groups. The gum thus produced is known as "hashab geneina" and is considered the best grade; it is referred to also as "gum acacia" and is the grade preferred in the American market. The gum collected from wild forests is known as "hashab wady", and because of the multiplicity of collectors whose work is necessarily uncoordinated, wady gum is generally of poorer grade and darker color.

Gum Senegal is obtained from *A. Senegal* and other but poorly defined species in West Africa. The trees cover great areas west and southwest of the Sahara and the French Sudan, extending through Senegal, Gambia, French Sudan, Ivory Coast, northern Dahomey and Nigeria. It is known also as "Berbera gum", "gomme de Galam", "gomme de Podor", "gomme de Tombouctou" and by a variety of other local names.

A large portion of the material reaching the market is from the country north of the Senegal River, a region which is easiest for the natives to penetrate and which is close enough to the coasts and the routes of the traders. In the region of the greatest gum collections abundant rains occur from July to November. The rainfall is so heavy that large areas become temporary swamp land. During these periods the trees grow luxuriously and become filled with sap with abundant new growth. The rainy season ends abruptly, being followed by a period of hot, dry, scorching, high velocity east winds. The rapid change in weather cracks the outer bark into many open fissures which become foci of infection for gum formation, and within a few weeks after the onset of the dry season there is a considerable accumulation of exudation.

The French system of sorting gum Senegal includes a considerable variety of grades. In general, the gum is yellower or redder than the relatively pale gum from the eastern Sudan. It is reputed to be not so clean as the Kordofan grades and is less favored by American importers and their customers. Furthermore, unless they are first subjected to mechanical and chemical processing, the Senegal grades are thought not to be so adhesive as those from Kordofan. They do, however, form solutions of greater viscosity and find a large European market.

Other Kinds of Gum Arabic. There appears to be general agreement that small amounts of gum are gathered in the Sudan and adjacent territories from *A. arabica* (Lam.) Willd. It is probable that gum from this tree, particularly that gathered from the forest areas, is unconsciously mixed with the gum from other species of *Acacia*. When not so mixed but gathered by itself it is often sold under the name "sunt". It is stated to be inferior to Sudan gum, being considerably weaker and more brittle, and

reaches the market as broken white or pale yellowish fragments. In the American market sunt does not appear to be important except as it occurs in admixtures.

Several species, and probably varieties, of *Acacia* furnish a form of gum arabic known as "suakim gum". It is from the regions adjacent to the western shores of the Red Sea, although some of the material may be brought by caravans from distant points. As a result of its relatively unsupervised collection it is ordinarily of inferior quality, although the quantities are important.

A. Seyal Del., widely distributed in the Sudan, is the source of a gum known as "talh", "talca" and "talba". It occurs in two forms, red and white.

Some gum is gathered from several species of *Acacia* in North Africa, but it is probable that considerable of the material that reaches there has been brought by caravans from south of the desert. It is known that some of these gums are gathered, not by organized caravans but by what might be termed "tramp" traders who transport gums as portions of miscellaneous cargoes. According to their points of entrance into commerce they are variously known as "Barbary gum", "Morocco gum" and "Mogador gum".

All these secondary gums and those of Sudan and Senegal are alike chemically and are regarded as gum arabics of different purities, varying also in degree of color, adhesiveness and viscosity.

Other Gums from Acacia

Several kinds of *Acacia* in India, probably both native and introduced species, also yield gums of economic value, though not at all so important industrially as gum arabic. They are included in that general term "East Indian gum" and must be distinguished from resins of India which are designated as "Pale East India", "hiroe" or "rasak". There appears to be random collection and transportation of these materials, and a large percentage comes to Bombay from Red Sea ports on the African coast. Some of it, however, is collected in various parts of India and finds its way to the trading and exporting centers. A particularly specific Indian gum is that designated as "babool", but in general the East Indian gums, because of their random collection and sorting, are of inferior quality and are often mixed with more important gums such as ghatti. *A. Catechu* (L.) Willd., which yields catechu extract, or cutch, an important brown dye, also produces a yellow-to-dark amber gum that is much used in India in textile applications as a substitute for gum arabic. Some of it reaches the commercial markets, but largely as an admixture in East Indian gum.

In Australia various native species of *Acacia* supply so-called wattle gum, production of which is secondary to utilization of the trees for wattle bark employed by tanners in the conversion of hides into leather. The gum is dark reddish and otherwise distinct from gum arabic in having a strongly astringent taste and an analyzable quantity of tannin derived from the bark.

Cape gum, gathered from acacia trees in Cape Colony, Union of South Africa, is somewhat similar to Australian wattle gum, and at times in the past has entered commerce in appreciable quantities.

In the western hemisphere samples of acacia gum from the southwestern United States or Mexico periodically appear on the market, and other samples occasionally are collected in Central and South America, particularly from *A. Farnesiana* Willd.

Gum Tragacanth

Gum tragacanth is perhaps the second most important commercial water-soluble gum, being surpassed only by gum ara-

bic and rivaled only by gum karaya. It is furnished by several species of *Astragalus,* thorny leguminous shrubs native to semi-desert regions of western Asia and southeastern Europe, but principally by *A. gummifer* Lab. which grows wild in the mountainous districts of Kurdistan, Iran, Iraq, Syria, Asia Minor, Armenia, Greece and Russia. In Iran the natives refer to the plants as "gavan", and to the gum as "katira", "katyra", "kathira", "katad", kettira", "kutera", "chitera" and "halusia". These names are used also in Afghanistan and India, and in the latter other gums are sometimes sold as "katira", "karai" and "katira-i-hindi" or "Hindu tragacanth". It appears that the gum is not a true secretion of the shrubs that produce it, but is the result of transformation of pith and medullary ray cells into a mucilaginous substance that exudes naturally or after the bark has been punctured or excised. It swells in cold water, forming a thick and ordinarily transparent jelly, and is less brittle, less glassy and duller in luster than arabic.

While the gum exudes spontaneously to the surface of the bark, it is obtained in commercial quantities by making punctures or transverse incisions in the main stems and older branches of the shrubs. Wedge-shaped pieces of wood are frequently forced into the incisions in order to enlarge the wounds so that the gum will flow more freely, and are left in the cuts a day or two before being removed. The gum swells by absorbing water, and the resultant pressure set up within the stem, rather than any biological force, causes the gum to exude. It is allowed to dry on the bark a few days before being collected and shipped to market. Collection is in May and June in the warmer districts; later in cooler areas where the best grades are obtained. Sometimes the plants are partly burned to stimulate excretion, but the product is inferior and the practice not general.

After collection and shipment to various markets, the miscellaneous pieces of gum are sorted into the following three general classes within which are the various commercial grades—common tragacanth, or "tragacanth in sorts": rounded or irregularly shaped tears or globules, representing gum that has exuded through naturally produced ruptures in the bark; vermicelli, or vermiform tragacanth: elongated, narrow, twisted strings or coils originating from stems which have been cut entirely across or from gum forced through rounded holes; flake tragacanth, also called "Persian", "Syrian" and "Leaf" gum: ribbon-like nearly colorless pieces exuding from slits made in the main stem near the root after clearing away the soil to a depth of about two inches; this is considered the highest grade on the market. Powder and aqueous solutions are also offered to the trade, the latter for certain specialized uses and generally treated to endow it with desired specific properties.

"Persian" tragacanth usually embraces the better grades from a number of areas. "Bagdad" and "Syrian" refer chiefly to gum which passes through Bagdad and is shipped through Basra. "Bushire", or "Persian", consists mainly of the gum from the Province of Fars in Iran and is shipped from Bushire. Turkish gum comes chiefly from Istanbul, other small lots occasionally are shipped from Bombay and Aleppo, and in Smyrna there is an important wholesale market where the gum is sorted before being sent to European distributing centers in Trieste, Bordeaux, London and Hamburg.

The annual United States consumption of gum tragacanth from 1929 to 1940 averaged about $2\frac{1}{4}$ million pounds, being imported chiefly from Iran and Turkey, with imports also from Russia,

Iraq, British India, Syria and Palestine. Prior to World War I Turkey was the most important source, but for many years since then Iran has supplied the greatest amounts, and its products are superior.

Tragacanth is one of the oldest drugs in Materia Medica, and its commercial use dates far back. It was known in the days of Theophrastus who described it three centuries before the Christian era. It has been official in every edition of the U. S. Pharmacopoeia since 1820, being used medicinally as a demulcent and pharmaceutically as an adhesive agent for pills and troches and for the suspension of insoluble powders. Other industrial uses are discussed later.

Indian Gums

Gums of various natures and obtained from different genera of plants are collected in parts of India. They constitute an important portion of the world's total production of gums and a large part of the American consumption. In most cases they are the exudations of large trees, whereas the gums of the arabic and tragacanth groups are collected from small thorny trees which in some cases are bush-like. Only a few of the Indian gums have reached the stage of continuous commercial collection, grading and organized trading on a recognized quality basis. Of them the first two next described are the most important. The others have only local uses, for the most part.

Gum Ghatti. This one, known also as "Indian gum" and "Ghati gum", is obtained from the trunk of *Anogeissus latifolia* Wall., a large tree, widely distributed in India and Ceylon, the leaves of which are rich in tannin and used for tanning in Bombay. Uses of the gum are similar to those of arabic, for which it is employed in India and certain other parts of the British Empire as a substitute in official pharmaceutical preparations.

Ghatti gum should not be confused with either Bassora or gum Sterculia, next described, each of which is sometimes referred to as "Indian gum".

Gum Karaya. Gum Karaya has become an important raw material in the textile, cosmetic, food and other industries, resembling gum tragacanth in that it swells in cold water to form an opaque gel. It has been used in the United States since the latter part of the 19th century, but large scale use here dates from World War I when the price of tragacanth was high. Some of the gum sold as tragacanth, even before World War I, has undoubtedly really been karaya. Imports into the United States are far in excess of those of tragacanth, usually more than double; in 1939 they were in excess of 7,600,000 pounds with a declared value of $575,000 at the ports of export. In this country the gum is known also as "gum kadaya", "Indian tragacanth", "Sterculia gum" and "India gum", but is not to be confused with "Indian gum" which is one of the names of gum ghatti. In India it is called "karaya", "kadaya", "katilo" and "kullo".

Gum karaya is a product of *Sterculia urens* Roxb., a tree native to India and found chiefly in Gujerat, in the central provinces and to some extent in the Central Indian Agency. Attaining a height of 30 feet, the trees grow in forests which for the most part are government owned but some of which are on private estates. The gum is obtainable throughout the year except in the rainy season, and the best quality is collected during the hot spell from March through the middle of June. Usually five or six incisions about two feet long and deep enough to reach the heartwood are made in the tree trunks by natives. The gum oozes into the incisions and accumulates in large irregular knobs which are collected about every three days. New accumulations then form in the same incisions, but if the gum is not collected,

the wounds heal and fresh incisions must be made elsewhere in the trees. Trees generally yield gum for eight or nine months, then cease for two or three years, after which they may again be tapped. The gum is collected by natives usually when there is scarcity of other work. It is taken to the villages where the merchants sell it to dealers in Bombay, and there sorting and grading are carried out, usually by women. Large lumps are broken with stones and sorted according to color and freedom from bark and other impurities. The best are white; the poorest dark brown to black.

Although the gum generally enters the United States as tears, nearly all that is sold to consumers is powdered, much of the bark being removed after powdering by an air blast. Colors vary from white to gray and often are reddish.

FIG. 4. Preliminary sorting of karaya gum. Bombay, India. (*Courtesy the Philadelphia Commercial Museum*).

Other Indian Gums. Many other trees of India also produce gums which are collected, and when gathered in sufficient amounts they reach the export market. If the amounts are great enough, the individual gums may be sold under their own names; if the quantities are insufficient for such disposal, the gums from different kinds of trees may be lumped together to give irregular shipments of non-reproducible quality. The chemistry of these less important gums is little understood, and at times their botany and the identity of their sources is the subject of dispute. They are referred to by that broad term, "Indian" or "East Indian Gum", that

encompasses so many exudation products of Oriental trees. More specifically and in brief they are as follows:

Butea frondosa Roxb. Dhak or palas tree. Furnishes a red gum known as "Bengal" or "Palas kino", or "Butea gum".

Chickrassia tabularis A. Juss. Chittagong tree. Reddish to amber gum.

Terminalia spp. Several species furnish yellowish to reddish gums.

Acacia spp. These have been mentioned in connection with gum arabic.

Anacardium occidentale L. Cashew. Native to tropical America but cultivated in India and yielding a reddish gum.

Pterocarpus Marsupium Roxb. Provides red kino gum. Commonly, however, "gum kino" is another name for dragon's blood which is a resinous substance obtained from the fruit of the climbing rattan palm *Daemonorops Draco* (Willd.) Bl. of eastern Asia and from the stem of *Dracaena cinnabari* Balf. of western Asia. Dragon's blood

FIG. 5. Selecting and sorting karaya gum. Bombay, India. (*Courtesy the Philadelphia Commercial Museum*).

Feronia elephantum Corr. Wood apple tree. Yellow to reddish gum.

Melia Azedarach L. China tree, Chinaberry tree, Pride of India. Gives an amber-colored gum.

Moringa pterygosperma Gaert. Horseradish tree. Ben. Furnishes moringa gum.

is not a gum but a gum-resin, and its commercial value for various purposes depends on its insolubility in water and its solubility in organic solvents.

Sapindus trifoliatus L. Yields soapnut tree gum, locally known as "ritha".

Cochlospermum Gossypium DC. Provides a very unimportant gum.

heated with water after extraction, serving, therefore, as thickeners in the same manner as gums do.

Vegetable ivory, or tagua, the hard seed of the Ecuadoran palm *Phytelephas macrocarpa* Ruiz & Pav., which is extensively used in making buttons, umbrella handles and other articles, owes its properties largely to the hemicelluloses of which it consists. Other hemicelluloses are gum-like and have commercial applications similar to those of the true gums. Since these uses are fairly specific, the hemicelluloses are industrially complementary to, rather than competitive with, the true gums, but their properties are such that they may fittingly

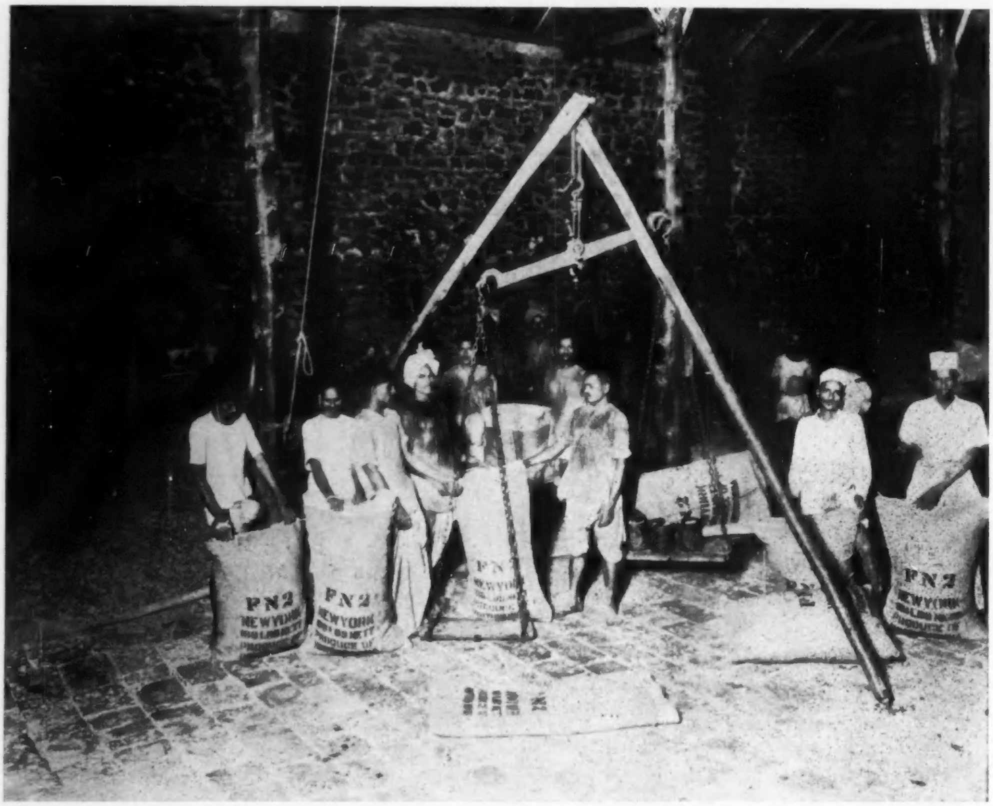

FIG. 6. Weighing and bagging karaya gum. Bombay, India. (*Courtesy the Philadelphia Commercial Museum*).

Hemicelluloses

Hemicelluloses are organic compounds consisting of hydrogen, oxygen and carbon which are chemically related to, but somewhat different from, cellulose and other carbohydrates, occupying an intermediate position among them. They are contained in the seeds and fruits of many plants, and swell enormously when

be classed with them in any general discussion. The only ones which have commercial uses are the following.

Locust Bean Gum. This gum is obtained from the seeds of the carob, or locust bean tree, of Mediterranean countries, and its extraction involves the following successive stages: gathering the pods and spreading them out in the sun to dry; removing the ten or twelve red seeds in each pod by hand or machinery and packing them for shipment; removal of the outside skin and embryo by passage between rollers which turn in opposite directions, sometimes preceded by treatment with dilute caustic soda and subsequent washing; roasting; boiling in water; filtering and evaporating the cooled cooked liquor which contains the dispersed gum; pulverizing and packaging the dry brittle gum obtained by these operations. The degree of purification varies widely in the different lots shipped to the United States, since they are prepared in several countries and in a variety of manufacturing plants. The purer grades, referred to as "locust kernel gum", contain less starch and other impurities. Solutions of the gum, of about 4% concentration, and containing a preservative, such as formaldehyde or phenol, are also marketed.

The gum is imported into the United States from Great Britain and France, as well as from other parts of the Mediterranean region. Before 1926 only small amounts were used here, but in 1939 imports of the gum reached an all time high of more than 4,000,000 pounds; the average annual consumption from 1929 through 1938 was somewhat in excess of 2,000,000 pounds. American imports of beans and pods, amounting to 1,500,000 pounds in 1939, are primarily for tobacco curing, not for extraction of the gum, since transportation costs for that purpose would be prohibitive, inasmuch as 1,000 pounds of beans yield only 100 pounds of seed from which only 35 pounds of gum is obtainable.

Locust bean gum is known also as "carob gum", "carob seed gum", "St. John's bread", "swine's bread", "gum hevo", "gum gatto", "jandagum", "lakoe gum", "lupogum", luposol", "rubigum", "tragon" and tragasol". The evergreen leguminous tree that furnishes it, the carob (*Ceratonia Siliqua* L.), is a native of Syria and has been cultivated in many Mediterranean countries from antiquity for its large pods which are used somewhat as human food but principally as a very important farm crop for forage. Theophrastus, in the fourth century B.C., in his history of plants, mentions it as being cultivated at Rhodes, and Dioscorides, in the first century A.D., praises the fruit in his Materia Medica as a laxative and diuretic. The pods are rich in protein and sugar, and form an important forage crop, readily eaten by stock and by the poor in times of scarcity. The molasses and sirup made from them are used for flavoring tobacco before it is cured, and fermented to make a wine or a hard liquor.

Guar. Several years ago, as the result of investigations at the Institute of Paper Chemistry, Appleton, Wisconsin, supplies of locust bean gum were required for the purpose of confirming on a commercial scale a number of observations in the laboratory. Studies with paper had revealed that the gum is a valuable paper-maker's adjunct in obtaining temporary wet strength in sheets, such as paper toweling, and that this gum facilitates hydration during the beating of various pulps. A study of the matter revealed an inadequacy in the supply of locust gum, and an attempt was accordingly made to locate other sources of mannogalactans (locust gum consists primarily of mannose and galactose). The services of the Soil Conservation Com-

mission of the U. S. Department of Agriculture were enlisted, and, as a result, numerous seeds were investigated for their potentialities. The most satisfactory of them were those of guar (*Cyamopsis tetragonolobus* Taub.), an annual drought-resistant legume, three to six feet tall, which has been cultivated in certain sections of India for centuries as fodder for cattle and horses. It was brought into the United States before World War I and has been studied on a limited scale, primarily as a green manure.

Guar gum resembles locust bean gum in being composed essentially of the complex carbohydrate polymer of galactose and mannose, but with different proportions of these two sugars. The practical value of this difference in the ratio of the two components is still the subject of study. Investigations carried out by the Institute of Paper Chemistry and numerous paper manufacturers have shown that guar flour is of value as a beater additive for improving the strength of certain grades of paper. It has been said that guar possesses properties which might be useful in warp sizing, printing pastes, and in certain finishing operations. The colloidal properties it possesses enable it to serve as a stabilizer or thickener in food products, such as ice cream and salad dressing.

In order to obtain the gum it is necessary to separate the gum-containing endosperm of the seed from the outer and largely fibrous portions. Milling methods have been developed for this purpose, and various grades of the gum can be isolated, ranging from products of high purity, to meet special requirements, to those of lower quality, designed for uses where high purity is not needed but where low cost of manufacture is important.

Flaxseed. The flax plant (*Linum usitatissimum* L.), extensively cultivated in many parts of the world for its fiber which is manufactured into linen, and for the linseed oil extracted from its seed for the paint and other industries, is also the source of a gum obtained in small quantities from the seed. This hemicellulose gum is of commercial value in the cosmetic and pharmaceutical industries because it acts as a demulcent and emollient.

Psyllium. Psyllium seed, which is extensively used as a mild laxative, is the source also of a mucilaginous gum that is readily extracted with boiling water. The gum serves in some instances as a substitute for gum arabic and tragacanth, and is utilized in the sizing of silk, printing of fabrics and manufacture of paper. It is obtained from at least three species of *Plantago*, namely, *P. Psyllium* L., *P. arenaria* Wald. & Kit. and *P. ovata* Forsk., the first mentioned being the most important. The first two are cultivated in France and Spain, the third in India, and in 1935 more than two million pounds of the seed were imported into the United States to be used principally as a drug.

Quince. Quince gum, also obtainable by boiling the seeds, has found value in the cosmetic industry as a demulcent in hand lotions, hair waving and cleansing lotions, and in medicinal preparations. The principal source is the quince (*Cydonia oblonga* Mill.) crop of Iran, smaller amounts coming from Iraq, Portugal and the Union of South Africa. Total imports of the seeds dropped from less than 222,000 pounds in 1941 to a little more than 154,000 pounds in 1942. In 1939, 63,869 bushels of the seeds were accumulated from the crop in the United States, principally in New York, Michigan, Pennsylvania and Maryland.

Iceland Moss. This lichen (*Cetraria islandica* L.), the economic value of which has been discussed along with that of other lichens in Volume 2 of ECONOMIC BOTANY, yields a hemicellulosic gum on boiling that has value in

cosmetic preparations and in the sizing of textiles, similar to that of Irish moss and the seeds of quince and psyllium. The whole lichens are pulverized by peoples of far northern latitudes and are incorporated into breads, gruels and other preparations. Considerable quantities have been used in the manufacture of sea biscuits which are said to be less liable to attacks by weevils than are other biscuits made only of wheat flour.

Miscellaneous Gums

Many cultivated trees, valued primarily because of their edible fruits, yield gums which show swelling properties and form jellies more or less transparent and uniform. In Europe, for instance, cherry gum is collected from *Prunus avium* L. and *P. Cerasus* L., the common cherry trees on the Continent, and at various times in the United States marketable quantities of the gum are offered as the result of off-season collecting by farmers and marketing organizations seeking profits from by-products of their fruit business. Supplies are not constant, but the gum finds application in pharmaceuticals. The cultivated peach, too, widely grown in the States from New York to Georgia, yields a hard reddish hydrophilic gum where the branches are bruised, or injured by boring insects. The same is true of plum trees. Gums collected from various fruit trees as well as the almond enter into the assortments of miscellaneous Indian gums and often constitute a mild form of adulteration of arabic ghatti and tragacanth. Syrian gum, sometimes designated as "carmenia" and not to be confused with the name "Syrian" as applied to flake tragacanth, is reputed to be the exuded masses from almond (*Prunus Amygdalus* Batsch.) and plum (*Prunus* spp.). It is often used locally in confectionery.

Other gums of minor commercial importance or used only locally, in their regions of usually crude collecting, for adhesives, as a size and cloth stiffener, in cosmetics and in pharmaceuticals are: angelique gum from *Dicorynia paraensis* Bentham, a large tree of northern South America; brea, or beira, gum from *Caesalpinia praecox* Ruiz & Pav., a small tree of northern Argentina; cactus gum from various species of *Opuntia* and *Carnegeia* in semi-arid districts of Mexico and the American Southwest; goma de cedro, cedro gum or cedar gum from the fragrant *Cedrela odorata* L. of the West Indies, the wood of which is used for cigar boxes; goma de guanacaste from the West Indian trees *Enterolobium cyclocarpum* Gris. and *E. ellipticum;* mesquite gum from various species of *Prosopis* in the American Southwest; mangrove gum from *Rhizophora Mangle* L., widespread in the tropics and semitropics; mimosa gum from several species of *Mimosa;* and a gum from the tree *Symphonia globulifera* of the West Indies and northern South America.

Seaweed Gums

The masses of seaweed that flourish to a depth of five fathoms in the coastal ocean waters of the world are raw materials for an increasing number of industries. For centuries they have been employed as agricultural fertilizers, human food, ingredients of pharmaceuticals and as a source of certain chemicals, namely, soda, potash and iodine by extraction, and, for a time, acetone by a fermentation process.

The extensive more recent utilization of these plants as a source of gum-like hydrophilic colloids under the names "agar", "carrageenin", "algin" and "alginates" had its origin in connection with World War I. These hydrophilic colloids are derived from two general groups of algae, namely, the kelps for algin and alginates, and the red algae for agar and carrageenin. The colloids thus derived have a number of similar properties, but also others which are

physically and chemically different and which render one colloid more suitable than others for specific applications. Both groups of algae furnishing them have been discussed in two articles in Volume 1 of ECONOMIC BOTANY, and only certain aspects of their utilization will therefore be mentioned here.

Kelps. Kelps are the large ribbon-like brown algae, some of which are occasionally found washed ashore. They were formerly an important source of iodine. In 1883 E. C. C. Stanford, an English chemist, was attracted to this industry as a possible source of chemical by-products, and he pioneered in the field of extracting them. His attempts, however, were unsuccessful, but in the course of his investigations he obtained by alkaline extraction a substance with unusual gelling properties. When the material was precipitated, filtered and purified, he found it to be an acid and named it "alginic acid". This material has become the basis of present day utilization of kelps. It is a dry substance, not a liquid, and under microscopic examination is seen to be fibrous in a manner similar to wood pulp.

Alginic acid, referred to industrially in its gelatin-like form as "algin", is today produced in the United States to the extent of more than two million pounds annually with a value of more than one and one-half million dollars. It may be in the form of crude pastes, as used for boiler-water treatment, selling for 5¢ to 7¢ per pound, or in purified flakes for 80¢ to a dollar or more per pound. The principal manufacturing establishments in the United States are the Algin Corporation of America, at Rockland, Maine, and the Kelco Co., at San Diego, California.

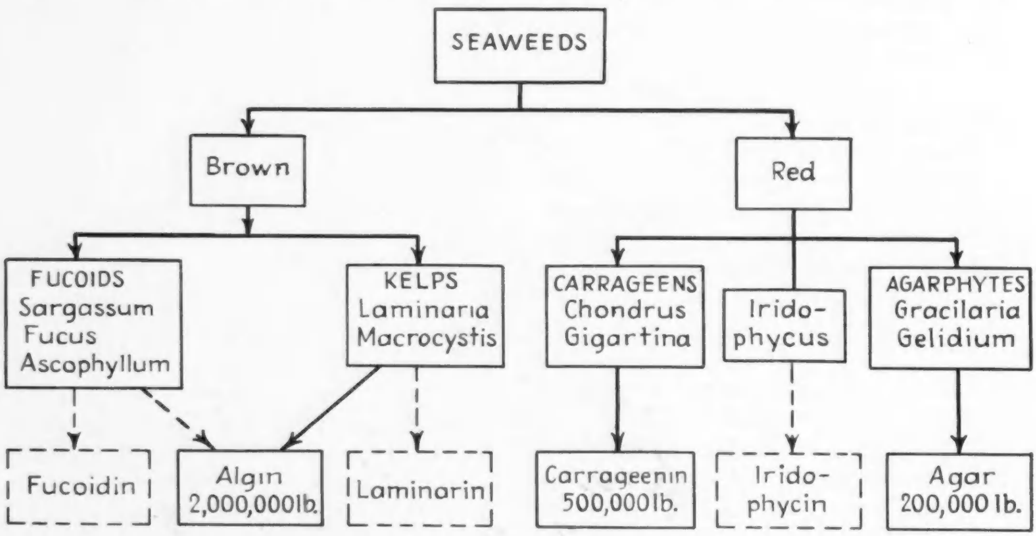

FIG. 7. The industrially important seaweed colloids and their sources. Broken lines indicate unimportant derivatives that may some day be of greater value.

The Algin Corporation and other concerns processing the seaweeds in New England depend for raw materials upon collections, made along the coast up to Nova Scotia, of the horsetail kelp (*Laminaria digitata* Lam.) and the broad-leaf, or sugar, kelp (*L. saccharina* (L.) Lam.). Gathering in the shallow coastal waters is by power boats equipped with grapple hooks so as to

operate at depths of 12 to 15 feet. Lesser quantities are collected from dories by hand dragging and raking as off-season work by fishermen. The best season for collecting is from June to the early part of December.

The Kelco Co. and others on the Pacific Coast depend primarily on the giant kelp (*Macrocystis pyrifera* (Turn.) Ag.) which grows over 100 feet in length and forms beds in the Pacific many square miles in area. The gathering mechanism is a motor-driven barge on which a modified under-water mowing machine is mounted. The machine has a horizontal blade, 10 to 20 feet wide, set four to five feet below the water surface. The kelp after it is cut is hoisted aboard by an inclined chain elevator. The cutter is mounted on the bow of the boat so that the cutting knife is ahead, and the boat at its beam is wider than the knife. The gatherer, or elevator, is directly behind the knife, and is chain-driven at speeds which are high enough to collect the kelp before the motion of the water carries it away. The edges of the elevator are equipped with knives so that the kelp does not jam at the sides and clog the cutter and elevator. Barge capacities of 300 tons are not unusual, and the kelp has been collected in amounts of several hundred thousand tons per year south of Point Conception, California. Kelp "farming" is carried on by cyclic cutting of the beds to permit natural replenishment.

Kelp beds are located below low-tide levels. Intertidal beds of other but much smaller brown algae, in the genera *Fucus* and *Ascophyllum*, are potential sources of seaweed colloids but have not yet acquired any commercial importance.

The extraction processes are rather complicated and are covered by patents. They all involve many steps and lead to the same ultimate products, namely, colloidal algin, calcium alginate, sodium alginate or other alginates. These products are commercially important because of their properties as emulsifying, suspending, jellying, thickening and bodying agents. One of the largest uses of algin in the United States is as a stabilizer for ice-cream. Its presence there induces smoothness of texture and prevents formation of ice crystals during storage. Algin finds wide application also in food products of a foam, jelly or emulsion nature, such as cakes, icings, chocolate milk and whipping cream.

Ammonium and sodium alginates have been widely suggested for casein emulsion paints. Sodium alginate, particularly in its cheaper and cruder form, is employed as an addition to boiler feed water to prevent incrustation. In this use calcium alginate precipitates are formed with the alkaline earth compounds in the water to give globular flocculent masses. These, with other compounds which settle out, give a soft pasty sludge which can readily be "blown down."

Algin and sodium alginate in many ways compete with the natural gums, such as arabic and tragacanth, in the preparation of greaseless lubricating jellies, hand lotions, sizing materials, pharmaceuticals and the many products which require thickening agents where viscosity increases are produced with small increases of solids contents. Being the product of chemical manufacture, the alginates are more consistently uniform than are the natural gums.

Considerable research on alginates for conversion into textile fibers has been carried forward. Such fibers do not compete with cotton or other natural fibers, or with rayon or nylon, for they readily dissolve when washed with soap or alkalies. They are of some interest in textile fabrication in designs which utilize the fibers in weaving and remove them by solution in finishing to obtain effects otherwise not possible. The prep-

aration of fibers and yarns from alginates and the weaving thereof, with subsequent removal, is a relatively expensive procedure which can be justified only in special and costly fabrics.

In addition to the foregoing uses, application of alginates has been either established or investigated in the creaming of rubber latex, particularly the synthetic; as a coating for cheese, meat and other food products; and in toothpastes, lotions, pastes and polishes.

Red Algae. The important red algae utilized for extraction of colloidal material are Irish moss, harvested for carrageenin, and the other forms which are gathered for agar.

Irish moss (*Chondrus crispus* (L.) Stackh.) is known also as "carrageen", "carragheen", "carrageen moss", "carragheen moss", "pearl moss", "rocksalt moss", "killeen", "pigwrack" and by a number of other names. It grows in tufted clumps, two to ten inches tall, attached to rocks below the low tide water level, or in intertidal pools, along the American and European shores of the North Atlantic. In their natural habitat of sea water the plants display various shades of purple or dark green with purplish tints, and in shallow pools in rocks adjacent to areas of high water the color may be drab olive. When dry the plants are somewhat stiff, and the fronds, normally flexible, tend to be horny.

Harvesting season is from May to September and is formed with long-handled iron rakes, the operators working in dories and scraping the moss from the surface of submerged rocks. A good mosser will collect about 400 pounds in four hours during ebb tide. The moss is subsequently spread out on sandy beaches, repeatedly raked and sunbleached, or is bleached chemically with sulphur dioxide or other agents; it is also marketed in a black or unbleached form. There are many gradations of quality, and the cleaning and bleaching operation must be properly handled before the moss can be sold to extractors. The gelatinous material subsequently extracted by boiling water and known as "carrageenin" is used in the manufacture of pharmaceuticals, cosmetic soaps, paint, boiler-water compounds, in nonsettling chocolate beverages (probably the greatest use), and in the brewing, textile, leather and other industries. Consumption of the dried seaweed in the United States for these purposes ranges from 800 to 1,200 tons annually, which means the gathering of 4,000 to 4,800 tons of wet weed. The value of the crop in Massachusetts, centering around the town of Scituate, was in excess of $100,000 in 1941, but from year to year the production varies widely.

Agar, which figuratively has hundreds of industrial uses and has an entire article devoted to it in Volume 1 of ECONOMIC BOTANY, is produced from red algae which are widely scattered off the seacoasts of Japan, China, Ceylon, Malaysia, Australia, Mexico, California, Lower California and North Carolina. In Japan it has been extracted, principally from species of *Gelidium*, since the seventeenth century, and prior to 1941 the United States depended almost wholly on this Japanese source for its agar, although there was one producer on the West Coast at San Diego, California. This Asiatic development accounts for some of its other names—"Japanese isinglass", "Chinese isinglass", vegetable isinglass", "seaweed isinglass", "Japanese gelatin", "bar kanten", "square kanten", "slender kanten" and others.

Three grades of Japanese agar are offered in the United States—Saghalien, Kobe and Yokohama. The first, from the Japanese part of Saghalien Island, is said to effect savings of sugar up to 30% in confections; it is imported in the least quantity and its price is the highest.

Kobe represents about 80% of the Japanese output and a far larger proportion of the American imports. Most of the Yokohama, or Shinshu, quality is consumed in Japan, not more than 30% being exported, principally to Europe. All three are available generally as strands, sheets, blocks, powder or in shredded form.

The seaweed from which the Japanese agar is extracted is collected from May to October by divers who make many descents during the day, cut the weeds free and return to the surface with bundles of them. The plants are then left on the beach three or four weeks to dry and bleach, and later are taken for manufacture to the mountains, for example, back of Kobe, where is found the right combination of cold nights and bright sunlit days to give the alternate freezing at night and the sun's thawing and bleaching action in the daytime. The manufacturing procedure involves cleaning the seaweed by beating and washing in cold fresh water until free of salt and most of the foreign matter. The material is then boiled for 30 to 40 hours to extract the glutinous matter and is allowed to settle undisturbed. Separation of grades is accomplished by scooping off layers without stirring; the top 70% usually furnishes the best grade. The solution is then poured into trays to cool and set, after which the jelly is forced through a perforated press. The resultant strips are next laid out to dry and bleach on shelves in the open or in covered open-sided sheds. The dried bleached product is sold either in strip form to the Japanese market or in ground form to the export trade.

By far the greater proportion of the American agar industry is located in the southern part of California. It began in 1919 with the founding of the American Agar Co. by seven Japanese in what is now Glendale. Mechanical refrigeration replaced the natural method of the Japanese procedure, and chlorine bleaching replaced that of the sun's rays. The raw material was *Gelidium cartilagineum* (L.) Gaill. from the San Pedro breakwater. Uneconomic operation as a result of too much hand labor resulted in commercial failure. In 1923 the plant was reorganized and the process mechanized by a successor who was responsible for American production from that year until 1926 but who terminated operations in 1933. In 1933 the United States Agar Co. was started in National City, Cal., to reprocess Japanese agar. This company subsequently became part of a fourth concern, the American Agar and Chemical Co., at San Diego, working on *Gelidium* from Mexico, Laguna, San Pedro and Redondo. A fifth outfit, Agar Products Co., of Los Angeles, lost its source of crude imported agar from Japan and turned to the nearby regions of the Pacific for raw material. In 1943 the Pacific Agar Co. began operations at Whittier, Cal., and increasing demand subsequently caused two factories in Mexico to come into operation. On the Atlantic Coast commercial quantities of *Gracilaria confervoides* (L.) Grev., suitable for agar extraction, are present in the region of Beaufort, N. C., and extracting factories have been set up at Beaufort, in New York and in Scituate, Mass.

The process of extraction and final preparation of agar for market includes many stages and careful manipulations, as depicted in Fig. 8. The chemistry of the substance is very complex and has not yet been fully worked out, but the material may be regarded as the calcium salt of a sulfuric ester of a colloidal carbohydrate complex.

C. K. Tseng, the author of one of the previous algal articles in ECONOMIC BOTANY, has estimated the distribution of agar consumption in the United States as follows:

TABLE 3.—DISTRIBUTION OF ANNUAL AGAR CONSUMPTION IN THE UNITED STATES (ESTIMATED)

	Pounds
Laxatives	100,000
Culture media	100,000
Bakery industry	100,000
Confectionery industry	100,000
Dental impression molds	75,000
Meat Packing	50,000
Emulsifiers	50,000
Cosmetics	25,000
Miscellaneous other uses	50,000
Total	650,000

Agar is a non-nutritive food, but is employed in food manufacture where bulk is desirable or where a hydrophilic colloid is useful because of its suspending, stabilizing, thickening or gelling characteristics. It serves to increase bulk in bakery products and is useful for low-calorie breads or biscuits for reduction diets for obesity or in non-starch breads for diabetics. In dairy products, sherbets, water ices and frozen confections, agar, as well as the other natural gums and hemicelluloses, such as that of locust bean, serves as a stabilizer. Agar acts more quickly than gelatin but has a low whipping point, in which respect it is not so good as are the natural true gums. It is not recommended as a stabilizer for ice cream. Probably the major non-competitive use of agar has been in nutrient broths and culture media of biologists.

Modified Celluloses and Starches

By various treatments cellulose and starch are industrially converted into products possessing gum-like properties that make them useful in many of the ways in which natural gums are utilized.

Cellulose is insoluble in water and does not display any swelling characteristic, but when treated with alkyl halides, such as methyl chloride or alkyl sulfates, after preliminary chemical treatment, it is converted into a cellulose ether with gum-like applications. A number of these cellulose ethers have been prepared, and some of them are available in commercial quantities.

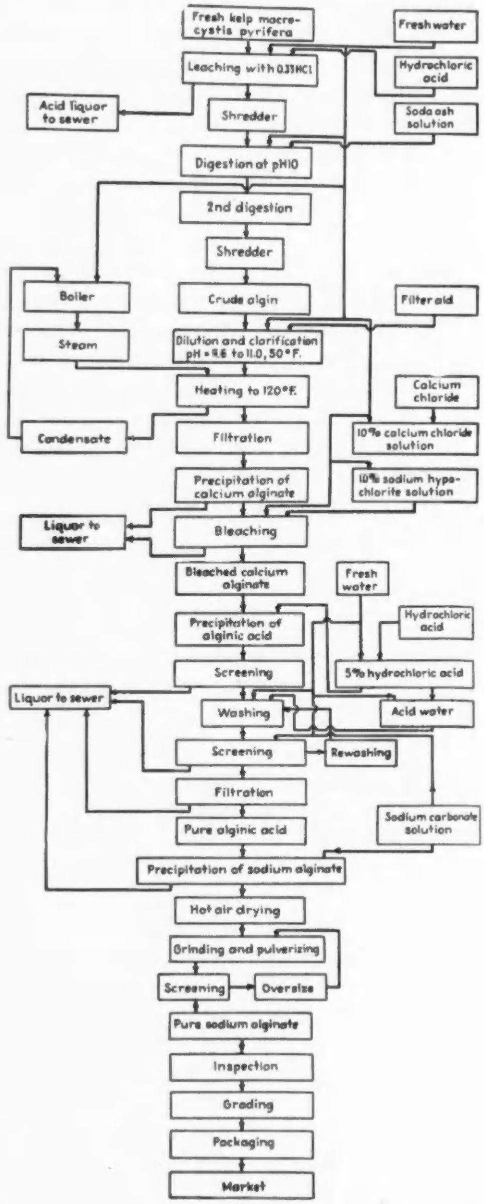

FIG. 8. Flow-sheet of the various operations in producing sodium alginate from the giant kelp, *Macrocystis pyrifera*, in California.

Methyl cellulose, for instance, has been suggested as a thickener or a mechanism

for increase of viscosity for textile printing pastes in competition with modified starches, dextrins and natural gums. It has been introduced into the textile industry under the trade name Colloresine.

When cellulose is steeped in alkali metal hydroxide solution up to six hours, alkali cellulose is formed, and when this substance is acted on by monochloracetic acid, there is a conversion to a white, granular, tasteless powder, designated "carboxymethylcellulose". The sodium salt of this powder is known as "sodium carboxymethylcellulose", "cellulose gum", "sodium cellulose glycolate", and by the trade names Carboxy Methocel, Cellocel and CMC. This salt is readily dispersible in water or in alkaline solutions so that thick highly viscous sols are formed whose characteristics differ in degree and chemical properties from those of water-dispersible proteins, vegetable gums, seaweed colloids and hemicelluloses. Since it is a hydrophilic colloid it has been suggested for the usual water-dispersible gum applications, namely, as a protective colloid in emulsions to prevent separation of the phases, in adhesives, finishing and sizing agents in textiles, paper coating and others.

Modified starches are the dextrins and British gums. They are products of the action of heat or of heat and chemical agents on starch by dry processes, or conversion products manufactured by suspending starches in water or cooking them to jellies and acting on these with chemical agents, either cold or at high temperatures. Dextrin was first made in 1804 by roasting starch in an attempt to find a substitute for gum arabic and gum tragacanth which then already were largely used in industry. British gum reputedly originated as a result of a fire in a starch storage building at a textile plant near Dublin, Ireland, in September, 1821. Part of the factory was destroyed by fire, and the starch in storage was roasted to a brownish yellow color. When this material was mixed with cold water it no longer had the characteristics of starch but dissolved to a viscous gummy liquid. The results were duplicated by heating starch in a cooking pot over fire, and the manufactured material was henceforth known as "British gum".

Up to 1870 gums from *Acacia*, particularly from the Sudan, were almost exclusively used for the gumming of papers, envelopes and stamps. At the time of the Mahdist rebellion in the Sudan and the Sudanese campaign between 1884 and 1898, the supply of gum arabic was short and unstable. Prices rose to such an extent that substitutes were imperative, and dextrin from Germany relieved the situation. The raw materials for dextrins are the starches of corn, sago, tapioca and potato; smaller amounts from other sources are also used. The dextrin products vary considerably as a function of the raw material and of the manufacturing operations. While potato starch is thought of as the easiest one to convert, disagreeable odors are produced by thermal processing. Tapioca, or cassava, starch is free from this objection in that the dextrin made from it is in most cases odorless and tasteless while giving good adhesive strength, solubility, color, viscosity and clarity. It is the dextrin used almost exclusively by the U. S. Bureau of Engraving and Printing as an adhesive on postage stamps. When sago starch has been refined by washing or chemical treatment, satisfactory dextrin may be produced from it. It is claimed that the dextrins from cornstarch are not quite so good for some specialized purposes as that from tapioca or purified sago, but for most applications cornstarch dextrins are competitive with those from other sources.

The trade differentiates between dextrins and British gums in that the latter

give higher viscosity dispersions, very thick masses or even non-flowing pastes. Some of these characteristics are owing to the presence of only partly converted starch. British gum may be made by simple thermal processing of starch without the use of a hydrolyzing agent, or with amounts much smaller than are employed for the preparation of dextrin. Typical hydrolizing agents are mineral acids—hydrochloric, nitric, sulfuric or mixtures of them; organic acids, *e.g.*, oxalic and formic; or halogen acids including hydrobromic. Acid salts and alkaline earth salts are also used as hydrolizing agents. British gums are usually somewhat darker than dextrins, being brown and often having a distinct burnt odor. Dextrins are often made from single starches, while British gums are commonly produced from mixtures of starches of various sources.

Gums in Cosmetics and Pharmacy

In the fields of cosmetics and pharmacy the hydrophilic colloids are used because of their mucilaginous or oily nature and their property of soothing enflamed or abraded membrane or skin and protecting them from irritation. In this capacity they are demulcents, or emollients. In lotions, ointments, pastes, salves, face creams and other cosmetic preparations they are suspending and emulsifying agents. Their quality of forming films upon evaporation, along with their ability to be plasticised or softened by other components, accounts for their presence in hair lotions, permanent waving compounds and bandoline.

The Pharmacopoeia of the United States lists gum arabic under Acacia; Agar; flaxseed, or linseed, as Linum; acacia mucilage as Mucilago Acaciae; tragacanth mucilage as Mucilago Tragacanthae; and tragacanth as Tragacanthae. The National Formulary lists Chondrus, Irish moss, Carrageen, Dextrinum Album and British gum. A number of unofficial lists, largely connected with the cosmetic arts, include cydonium, or quince seed; and karaya as Indian Tragacanth or Gum Sterculia. Other unofficial pharmaceutical listings include Psyllium which is in the British Pharmacopoeia Codex of 1923.

In principle the gums are interchangeable in their many uses ranging from laxatives to hair-wave lotions, but some of them are better suited than others to certain of these outlets.

Gums in Paints and Other Coating Compositions

Ancient Hebrew texts mention the decorator who used soured milk, the important constituent of which for that purpose is casein, and since the latter part of the nineteenth century factory-made casein paints in powder form have been sold in the United States. In recent years, however, and only after much development work, hydrophilic colloids and modified celluloses have found use in the paint industry in place of casein. The colloids are alginic acid and its sodium and ammonium salts, and the modified celluloses are sodium carboxymethylcellulose, aluminum carboxymethylcellulose and hydroxyethylcellulose. They do not constitute a major ingredient in the formulation of water paints, but nevertheless are of importance because of their stabilizing effects on emulsions of paints, waxes and numerous other products. In these uses they serve as thickeners, protective colloids or as film formers. As film formers with no modifying agents added, their use in the paint field is limited to a few special items, such as binders in fire-resistant paints where water-resistance is not essential.

The alginates have been incorporated in asphaltic paints and varnishes, shellac emulsions and waterproofing compositions in an emulsified form. Gum arabic has been employed in paints as a

glaze and for emulsifying oils, and other kinds of protective coatings have included natural gums in their make-up.

Gums in Textile Operations

Although natural gums have many uses in the textile industries, starches and dextrins find much greater use in the same applications, and frequently the gums are used as a supplement to starch, chiefly to toughen the starch film. Whichever are used, they are employed in two capacities—as thickeners and as sizing.

Textile color designs are obtained either by weaving or knitting colored yarns into the material, or by printing. In printing, the woven cloth, after being de-sized, bleached, mercerized or dyed, and dried, is printed upon by a variety of methods. Most of them, including the most important one, roller or machine printing, require color pastes which consist of thickeners, water, dyes, mordants, dyeing assistants and other ingredients. The thickeners fall into two broad groups. In one are those used solely as thickening agents and later removed as completely as possible from the fabric. Their function is to act as vehicles for carrying the color to the cloth and to prevent spread of the color by capillarity beyond the desired areas. They must not, however, have any affinity for the colors or mordants with which they are mixed; otherwise, on being subsequently washed out of the printed fabric they will carry along much of the color. Arabic, Senegal, tragacanth, karaya and locust bean gums, starch, flour, dextrin, British gum and sodium alginate are in this group. The other group acts as both thickening and fixing agents, remaining on the cloth as an integral part of the finished color. In this group are albumen and casein, non-plant materials, which are both coagulated by heat. By steaming they change to an insoluble form and fix the dye on the fiber.

Formulation of the printing color paste must fulfill requirements of a range of viscosities, body and other characteristics. This requires skill in selection of the ingredients and in the formulation. The printing paste must fill the engravings of the design rollers and permit rapid removal of excess. The paste must be pressed into the cloth, yet remain within the limits of the desired pattern, and it must permit the color to be fixed. The ability of a printing paste to give a fine line, a delicate design, lightly engraved blotches, heavy blotches, a blending of colors, a sharp definition of colors, penetration of color to the back of the cloth, and a great many other desirable qualities is in large measure dependent upon the thickening used. For cotton the natural gums are too expensive, and the cheaper starches and British gums are used.

Sizing, or slashing, consists of the treatment of warp threads with a solution that forms a thin layer of binding material on the yarn in order to hold together all loose fibers and strengthen the yarn for weaving. The principal gums used in cotton sizing in order of importance are locust bean, karaya, tragacanth and arabic; also the starches of corn, potato, tapioca, rice, wheat, sago and sweet potato. Locust bean is the most used, followed by karaya.

Turkish or Oriental Tobacco

Commercial production of Turkish varieties of tobacco in the United States is still a thing of the future, but investigations in that direction are being conducted.

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Historical Introduction

None of the many species of *Nicotiana*, except *N. rustica* and *N. tabacum*, is grown for the production of commercial tobacco, and such use of *N. rustica* is very limited, since it is utilized mainly as a source of nicotine for insecticides. The several botanical varieties and all the agronomic varieties of "ordinary" tobacco grown throughout the world, some of which are strikingly dissimilar in appearance, belong to one species, *N. tabacum*. This species, therefore, must be considered as an exceedingly plastic one, and its plasticity may be a result of its being a natural hybrid, as indicated by genetical evidence. Moreover, as is widely appreciated, the agronomic varieties have arisen partly by selection and hybridization and partly by adaptation to environmental differences in different parts of the world. As might be anticipated, certain of these varieties are also radically different from all the others in physical and chemical properties. Consequently all those having closely similar properties and similar use in manufacture and in international commerce belong to the same type. Commercial types, to mention a few only, bear such names as the following: Burley, flue-cured or Virginia, cigar filler, cigar wrapper, sun-cured, and Turkish or oriental.

The oriental tobaccos, which include several hundred varieties, are grown in a region generally known as the Near East, comprising Greece, Romania, Bulgaria, Russia (Crimean area), Turkey, Iran, Irak and Egypt. It is not definitely established when tobacco culture was first initiated there, but it probably dates from early in the 17th century. Oriental tobaccos were never greatly in demand in world markets during the succeeding 300 years, and, during this long period, the expansion of the tobacco industry in the Near East was slow and quite uneventful.

Until approximately 30 years ago the quantities of oriental tobacco imported into the United States each year were relatively small, and such tobacco was employed here almost entirely in the manufacture of all-Turkish cigarettes. Then, just prior to the outbreak of World War I, to dispose of accumulated stocks, certain manufacturers blended oriental tobaccos with domestic types to make cigarettes. Such blended cigarettes found immediate public favor because of improved aroma, better combustibility and better flavor. In fact, the popularity of blended cigarettes and blended pipe tobacco has increased rapidly each subsequent year. Coincidental with the rapidly increasing demand for blended smoking tobacco in the United States, there was a marked increase in tobacco production in the Near East, to the extent that when World War II began the annual crop there exceeded 100 million pounds. A large proportion was being purchased each year by American tobacco manu-

facturers. As a consequence of the lack of facilities for shipping and the radical changes in price structure occasioned by the war, the entire oriental tobacco industry became greatly disrupted. Whether it can again be stabilized to approximate pre-war conditions remains quite unpredictable and problematical.

During this period of rapid expansion, just mentioned, American and foreign tobacconists fostered the idea that tobacco having the qualities of oriental tobacco cannot be grown in any other portion of the world. A variety of reasons in support of this opinion was assigned. By and large, these reasons centered around obvious differences between different tobacco-growing regions, such as those of soils, prevailing temperatures, distribution of rainfall, and techniques of curing and subsequent processing. Published information, based on adequate experimental studies, regarding the production of oriental tobacco in the Near-East is meagre. At least such information as has come to hand, when critically appraised, has little value in determining the possibility of producing tobacco having the features of the oriental type in any region outside the Near East. Unfortunately the impact of opinions expressed by tobacconists and others with commercial interests to the effect that such tobacco cannot be grown elsewhere was tremendous, especially when their statements were employed as propaganda. In extenuation it may be said that actual field trials, involving the expenditure of thousands of dollars, have been made to grow oriental tobacco in the United States, and the results, showing lack of success, have been cited to support these opinions. When, however, the procedures involved in these trials are critically examined, the work must be appraised as quasi-scientific and quite inadequate, mainly for the reason that it shows lack of evidence of having been based upon fundamental knowledge of the tobacco plant itself, of its culture and of the factors correlated with "quality" in Turkish tobacco.

Elsewhere throughout the world, except in Rhodesia, no serious attempts have been made to cultivate Turkish tobacco. There in recent years the venture has attained the proportions of being commercially successful.

Experimental Findings

In 1939 a group interested in tobacco research, of which the writer is a member, decided to undertake a study to determine whether tobacco of the Turkish type might be grown in the southeastern United States, but only after having carefully considered the foreseeable difficulties involved in such a venture and the possible economic consequences. This study, employing both field and laboratory experiments, has now been in progress for nine years. In brief it has been established that tobaccos quite like those imported from the Near East can be grown in the Piedmont and Mountain Areas of Virginia, North Carolina and South Carolina. The rationale underlying all the procedures employed, just as in the production of other types of tobacco, has not been resolved. Such definitive progress as has been made has been recorded, in part, in some detail (1–8). It seems best at this point to state categorically the most significant of these findings and to leave until afterward their application to cultural practices. These findings include the following:

1. Varieties of tobacco long established in the Near East yield a product that is superior in quality to that from varieties that have been introduced there recently. Varieties long grown in the Near East, if planted in the United States, are found to be entirely unlike any commercial varieties now being

planted here. On the other hand, varieties recently introduced into the Near East, if planted in the United States, are recognizable as quite like some of the varieties now being grown here.

2. There are four primary groups among oriental tobacco: Samsoun, Smyrna, Kavalla, Xanthi. Experienced tobacconists, when given cured leaves to examine, not only readily distinguish between these groups but are able also to identify by name many of the varieties within each group.

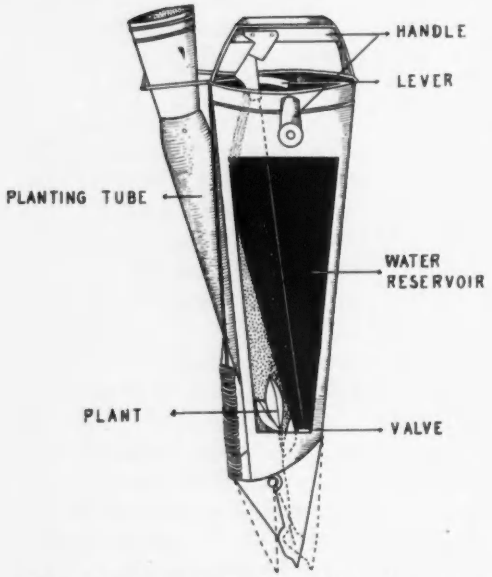

FIG. 1. A hand-planter, useful for transplanting tobacco seedlings. Survival is insured by watering each seedling while transplanting.

3. Considerable differences, as in height, time of maturing, leafiness, leaf shape, type of insertion of leaves and hairiness of leaves, exist between plants within any named variety of oriental tobacco. Kinds that are different in these features from the parent stock have been obtained by selection, but it has not been possible to secure complete similarity of progeny.

4. The elements of which "quality" in different types of tobacco is constituted, or the features with which quality is correlated, remain only partially analyzed and evaluated. But from the viewpoint of manufacturers, quality in oriental tobacco includes, as essential characteristics, aroma, combustibility and flavor.

5. Seasonal factors modify quality in oriental tobacco. Rains in excess when accompanied by continuously overcast skies unfavorably affect the development of tobacco having best quality, whereas the production of vintage crops is promoted by dry hot seasons.

6. The rate of growth of oriental tobacco for development of best quality is continuously slow throughout the entire season. When such growth is graphically represented, the growth curve is sigmoidal, although it tends to approximate a straight line.

7. Varieties of oriental tobacco differ strikingly in duration of the growth period, some requiring 30 to 40 days longer than others to reach complete maturity. In general, late-maturing kinds are taller, more robust, have the largest number of leaves, and when cured, their leaves are the most aromatic, but they bear the smallest number of flowers and capsules.

8. Oriental tobaccos are best harvested by removing the leaves as they mature, a few at a time, beginning with the lowermost and progressing upward on the stalk. Harvesting in this manner is called "priming." The leaves are air-cured, and curing is customarily hastened by exposure to sunshine.

9. To date there are no analytic procedures by which to gauge maturity. It is determined empirically. Immature leaves and over-mature ones, when cured, differ markedly from mature ones in texture, color and aromatic properties.

10. The uppermost leaves are generally of the best quality, and those borne near the base of the stalk are of poorest quality.

FIG. 2 (*Upper*). A field of oriental tobacco about four weeks after transplanting.

FIG. 3 (*Lower*). Harvesting oriental tobacco by removal of leaves as they mature.

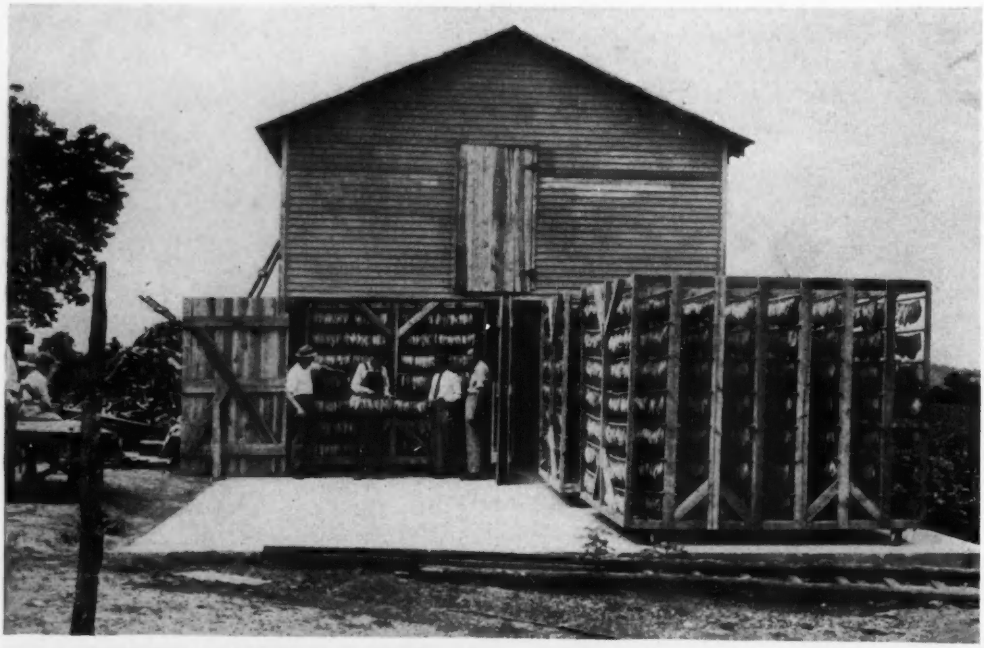

FIG. 4 (*Upper*). Curing and storage barn. The racks are moved out of the barn to facilitate curing, and are returned at night or to avoid injury from rain.

FIG. 5 (*Lower*). Stringing oriental tobacco by use of a long needle. In the background are strings of leaves attached to sticks.

11. Leaves having the largest surface area are produced along the median stalk region, and are progressively smaller toward the extremities.

12. Each leaf, except a few juvenile ones near the base, on any plant, regardless of leaf size, tends to have the same number of glandular hairs. As an outcome the population density of such hairs is greatest on the smallest leaves, *i.e.*, those borne near the top of the plant.

13. Aroma of oriental tobacco seems to be traceable primarily to the exudate synthesized by glandular hairs. The chemical nature of this exudate is not fully known, but it is a resinous complex containing ethereal oils which presumably undergo polemerization and oxidation slowly during curing and aging.

14. The density of hair population is heritable, but the number of hairs per leaf may be modified by environmental factors, such as spacing of plants and illumination. It follows that volume or quantity of aroma is to a degree controllable. There is evidence to indicate that quality of aroma is also controllable but to a lesser extent.

15. The differences in quality of leaves borne at different levels on the stalk are not traceable alone to differences in density of population of glandular hairs. There are also differences the causes of which are internal.

16. The removal of leaves in harvesting disturbs the leaf-stem-root balance and in consequence upsets the physiologic equilibrium of the entire plant. Compensatory adjustments or changes are therefore induced in the leaves remaining to be harvested. Such changes become progressively greater with each successive priming of leaves. As a consequence the leaves of each priming are chemically different from those of all others.

17. Oriental tobacco is not topped, *i.e.*, the flower stalks are not removed, because the physiological unbalance induced by topping results in undesirable physical and chemical modifications in the leaves.

18. Internal factors which regulate metabolism govern vegetativeness and reproduction in a tobacco plant. These factors are anti-complementary or oppositional. The point of inflection of the growth curve marks the stage at which the opposed factors are in balance. The factors are unbalanced in favor of vegetativeness during development of the leaves borne along the lower portion of the stalk, and in favor of reproduction during development of the upper leaves.

Application of Findings to Field Practices. Planting. Proper spacing of plants in the field is very essential in growing oriental tobacco because the plants when closely spaced grow slowly, and as a result the leaves are of small size, of desired texture and have the optimum hair population and chemical composition. The number of plants per acre should range between 50,000 and 70,000. If the distance between rows is 20 inches and that between plants within the row is 5½ inches, the number of plants per acre will approximate 60,000. Each plant, depending upon the variety, produces from 20 to 40 leaves, and from 700 to 2,000 cured leaves are required to weigh a pound.

Soils and Preparation of the field. The fertility level of fields in which oriental tobacco is to be grown is also an important practical consideration. A slow growth rate that can be controlled may be obtained by employment of infertile soils. For these requirements clay soils have been found preferable to sandy soils. Then, to provide a supply of essential minerals requisite for satisfactory yield and quality, well decomposed manure, six to eight tons per acre, may be applied. In general, when the

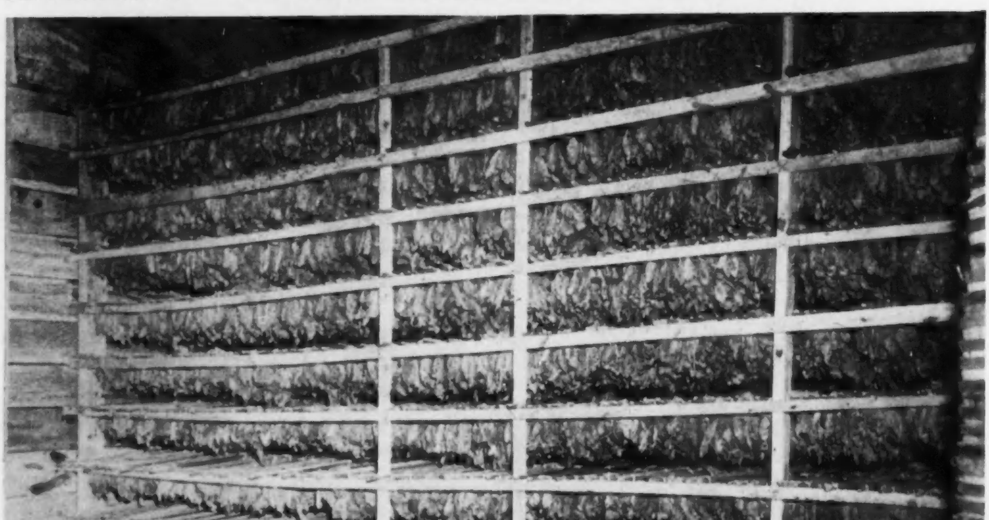

FIG. 6 (*Upper*). Portable racks containing sticks of curing tobacco.

FIG. 7 (*Lower*). Racks showing proper placement in storage of sticks of cured leaves. Such tobacco is ready to be baled.

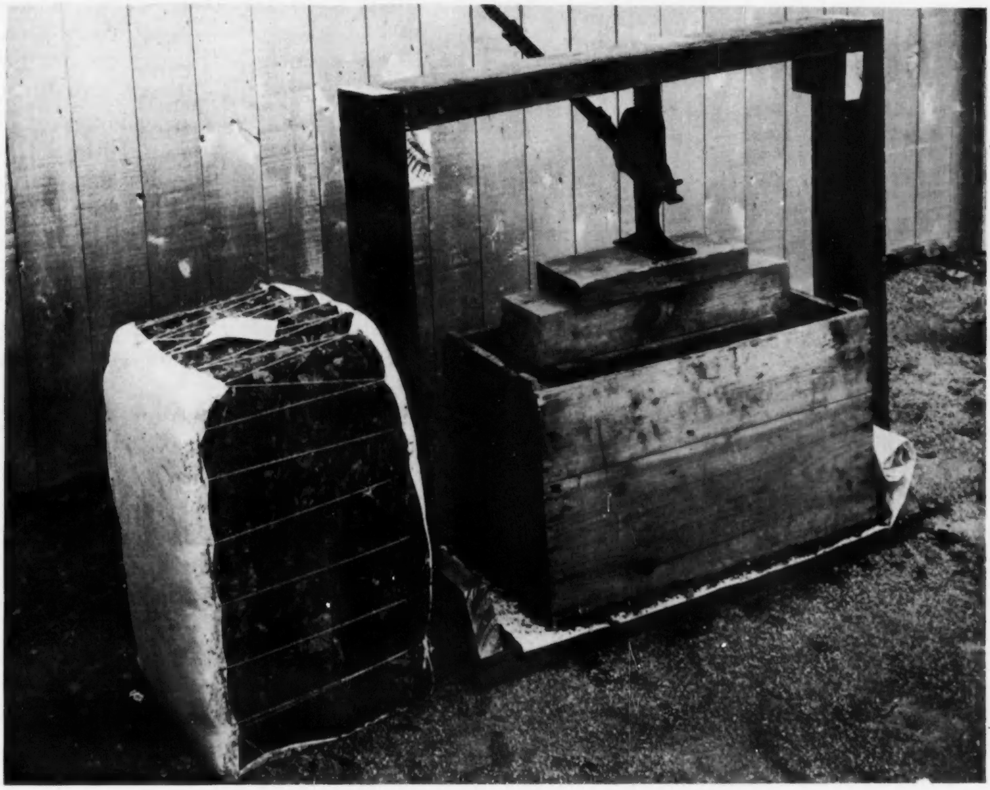

FIG. 8 (*Upper*). Bales of oriental tobacco undergoing aging in storage.

FIG. 9 (*Lower*). A press box and an automobile jack to compress the strings of leaves.

fertility level is raised by use of mixed commercial fertilizer, the quality of the cured leaves is undesirable. To supplement manures, however, potash in the form of sulfate of potassium, using 80 to 100 pounds per acre, is advantageous. In the presence of sufficient potassium cuticularization of the leaves is increased and quality, especially texture and combustibility, is thereby enhanced.

For best results the fields should be plowed, disked and manured well in advance of planting to the extent of establishing a good state of tilth. If the

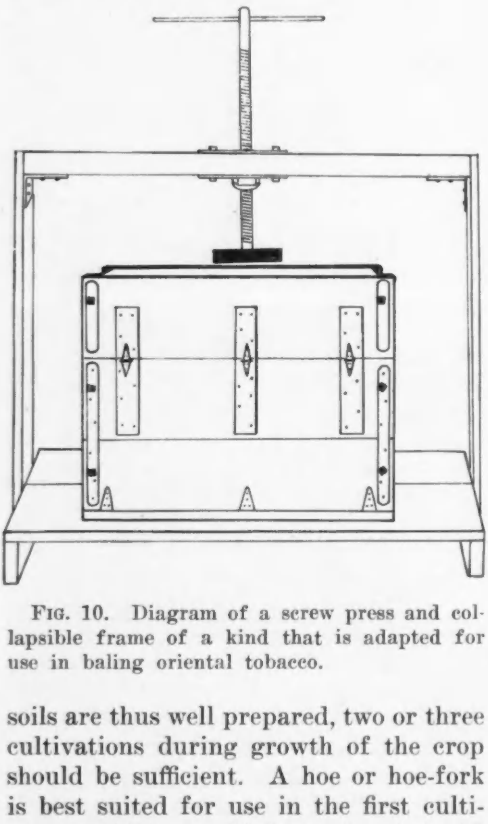

FIG. 10. Diagram of a screw press and collapsible frame of a kind that is adapted for use in baling oriental tobacco.

soils are thus well prepared, two or three cultivations during growth of the crop should be sufficient. A hoe or hoe-fork is best suited for use in the first cultivation which should be made 10 to 15 days after transplanting. Subsequent cultivations are best made by use of a horse-drawn cultivator of a kind having two or three bull-tongue points or shovels.

Harvesting and Curing. The lowermost leaves will be sufficiently mature to harvest approximately 50 days after transplanting. The topmost leaves may not be harvested until four to eight weeks later, depending upon the variety of tobacco and the prevailing weather. The leaves must be threaded onto strings as soon as possible after they have been harvested. In so doing a long needle is used to pierce the midribs. The strings of leaves are next attached to sticks or laths which are closely hung in a shed to permit the leaves to wilt and yellow. Proper wilting and yellowing are dependent upon maintenance of suitable relative humidity of the ambient air within the shed and of controlling air movement. If the humidity is too low and the air circulates too freely, the leaves will not yellow satisfactorily but will become dry; at the opposite environmental extreme, droplets of moisture may accumulate on the leaves, and and the tissues will then become discolored.

Wilting and yellowing should be accomplished after two days, whereupon the leaves should be placed on curing racks and exposed to direct sunshine. Curing requires from five to ten days if the weather is favorable. Unless the leaves are protected against dews and rains during curing, they become darkened. For this reason it is essential that the curing racks be portable or readily movable so that the curing tobacco can be moved under shelter at night and also during daytime when rains are imminent.

Once the leaves are thoroughly cured, the sticks of tobacco may be removed from the racks and placed in dry storage. Storage is suitable only if it is well ventilated and if the tobaccos remain dry during wet weather. Otherwise the tobacco may become damaged by molds.

Baling and Grading. Specially constructed frames or boxes and a mechanism for pressing are necessary for baling. At time of baling the moisture

content of the leaves should be such that they will not break on being handled, and yet they should be sufficiently dry to rattle. In baling the strings of leaves are compacted into the box and the bulk is then covered with burlap. If growers bale in this fashion the bales may then be moved to a factory. It is advisable to keep the primings separate, for by so doing grading at the factory is greatly facilitated. There the bales are opened, the strings are removed, the leaves are sorted, and again the tobacco is baled and stored to permit aging. During aging the bales are variously turned and stacked, a process called "manipulation". Aging requires for completion a period of a year to several years.

Literature Cited

1. Bentley, Nancy J., and Wolf, F. A. Glandular leaf hairs of oriental tobacco. Bull. Torrey Bot. Club **72**: 345–360. 1945.
2. Darkis, F. R., and Robert Mattison. Aromatic tobacco. Duke Univ. Tobacco Bull. 1. 1947.
3. ————, *et al.* Turkish tobaccos. I. The characteristics and chemical composition of imported types. Ind. Eng. & Chem. **39**: 1631–1642. 1947.
4. Wolf, F. A. Further consideration of glandular hairs and of their significance. Bull. Torrey Bot. Club **73**: 224–234. 1946.
5. ————. Growth curves of oriental tobacco and their significance. Bull. Torrey Bot. Club **74**: 199–214. 1947.
6. ————, and E. F. Jones. Comparative structure of green leaves of oriental tobacco at different levels on the stalk in relation to quality upon curing. Bull. Torrey Bot. Club **71**: 512–528. 1944.
7. ————, and J. R. C. Brown. Assay of certain oriental tobacco varieties. Jour. Tenn. Acad. Sci. **23**: 133–138. 1948.
8. ————, and F. T. Wolf. The origin of tobaccos of the oriental type. Bull. Torrey Bot. Club **75**: 51–55. 1948.

Utilization Abstract

Soybeans. In late 1947 the Chemical Division of General Mills, Inc., initiated commercial production of polyamide resin from soybean oil. This new product "is a tough, heat-resistant plastic, used primarily as a water and vapor sealer and as an adhesive surface coating for paper." It was the Northern Regional Research Laboratory of the United States Department of Agriculture that pioneered the manufacture and industrial utilization of polyamide resin from vegetable oil. In **1943** that organization developed a polyamide popularly known as Norelac, worked out unit processes and practical flow sheets for manufacturing the product and uncovered many potential uses for it. General Mills entered the picture at that time by launching a research program directed toward improving Norelac and by making pilot plant quantities of the resin available to industry.

"During World War II, this polyamide resin served as an ingredient in some of the hot-dip stripping compounds which protected Army and Navy equipment and spare parts against corrosion during overseas shipment. Applied while hot, these compounds hardened to a solid film as they cooled and could be easily stripped off when the equipment reached its destination".

The greatest peace-time application of polyamide resins is in packaging. (*A. G. Hovey, Chemurgic Digest 7(1): 18. 1948*).

Coir Dust or Cocopeat—*A Byproduct of the Coconut*

This material, now being produced commercially in Puerto Rico, has value as a mulching, rooting, soil-conditioning and seed-germinating medium.

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For hundreds of years natives of tropical countries have gathered coconuts (*Cocos nucifera* L.) and dehusked them in order to get at the edible contents of the nut itself, normally discarding the husk. In some countries, notably India and Ceylon, the husks have at times been soaked in water to loosen the fibers of which they are exclusively composed, and the fibers have then been separated by pounding for manufacture into cordage; or they have been separated by holding the husks against a revolving wheel armed with spikes. The latter method produces very short fibers unsuited for cordage but adaptable to conversion into the familiar coco door-mats abundantly imported into the United States. A by-product of this short-fiber production is a mass of tiny, brown, irregularly shaped particles, known in the British Empire as "coir dust". Because the term "dust" to most people implies an undesirable quality and has no connection with the coconut, and because this so-called "dust" has many characteristics of horticultural peat, it is here suggested that this valuable material be known as "cocopeat".

A search of the literature has disclosed only four authors, working chiefly in India and Ceylon, who discuss its use. One of them recommends it, when well leached, to increase the organic matter content of potting soils. He also notes its slow decomposition and beneficial mechanical effect in improving soil drainage. Another mentions its use for bedding animals, as a packing material for nursery stock and for insulation. A third author describes its use in the fertilization program for coconut plantations where it is placed in shallow trenches around trees to which animals are tethered, absorbing their urine and holding it for use by the tree.

In the only known publication dealing solely with the material, analyses show that it contains less than one percent of any of the major nutrients and thus indicate that it can not be sold as a fertilizer. These data also show that it contains approximately 40 percent lignin and only 12 percent pentosans. The author of them interprets this low pentosan-to-lignin ratio as an indication of extremely slow decomposability and suggests that the decomposition process could be stimulated by addition of nutrients and materials high in pentosans, such as grasses. He also showed its ability to improve the moisture-holding capacity of sandy soils when, by adding only two percent of cocopeat to a sandy loam, the moisture-holding capacity of the soil was increased from 24.3 to 33.2 percent, or nearly 40 percent. This increase is not surprising, for he found the moisture-holding capacity to be over 800 percent on a dry-weight basis.

Until recently cocopeat was practically unavailable in the Western Hemisphere.

A modern coconut fiber factory established in Mayaguez, Puerto Rico, is now producing this material in large quantities as a byproduct. Although only preliminary tests have been made with it at the Federal Experiment Station in Puerto Rico, it has been found sufficiently useful to practically eliminate the necessity of importing peat for horticultural uses.

An analysis of cocopeat from the above source is reported in Table 1. A sample

TABLE 1

MINERAL COMPOSITION OF THREE FRESH SAMPLES OF UNSCREENED COCOPEAT[1]

Sample	*Ash*	*Ca*	*Mg*	*K*	*P*	*N*
	%	%	%	%	%	%
1	2.39	0.42	0.63	0.82	0.07	0.11
2	2.45	0.39	0.70	0.25	0.09	0.11
3	2.48	0.31	0.65	0.84	0.09	0.11

[1] Analyzed by R. Fernandez Pol, Collaborating Chemist, Federal Experiment Station, Mayaguez, Puerto Rico.

representing the oldest material available which had weathered approximately four years in the open was very similar in composition, indicating extremely little decomposition. Cocopeat is fairly well supplied with iron and manganese, and has been shown to contain 17 parts per million of water-soluble manganese, 33 ppm of exchangeable and 63 ppm of reducible manganese. The iron content was 100 ppm of water-soluble, 78 ppm of exchangeable and 81 ppm reducible iron. It is only slightly acid, with pH values ranging from 5.7 to 6.7(2).

As pointed out by Joachim, cocopeat is very slow in decomposing. It requires less frequent replenishing than most other mulching materials, but is gradually mixed with the soil by the action of worms and other soil organisms, eventually improving the physical condition of the soil.

Macmillan makes a special point of using well decomposed cocopeat, possibly implying the existence of something toxic in the fresh material. In order to test this point, a cylinder of fresh cocopeat three feet long and 14 inches in diameter was enclosed in fine-mesh chicken wire. Tap water was poured through the cylinder to leach out any soluble material. The leachate was used to water one of two flats of sand in which identical seeding had been made. The other was watered only with tap water. The results are shown in Table 2.

TABLE 2

HEIGHT OF SEEDLINGS GROWN IN SAND WITH AND WITHOUT WATER EXTRACT OF COCOPEAT 30 DAYS FROM SEEDING

Species	*Average height of seedlings*	
	With cocopeat extract	*With tap water only*
	Inches	Inches
Bauhinia purpurea L.	2.5	0.8
Bauhinia violacea Hort.	3.0	1.6
Sterculia apetala (Jacq.) Karst.	7.1	4.2
Couroupita guianensis Aubl.	2.1	1.1
Cassia spectabilis DC.	2.1	1.0
Erythrina berteroana Urban	2.4	1.2
Average height of all seedlings	3.45	1.65

It is evident that, quite contrary to causing any deleterious effect, the early growth of seedlings was stimulated by the cocopeat extract. The treated seedlings averaged 3.45 inches in height, while the untreated averaged only 1.65 inches. The percent germination was unaffected.

Cocopeat has been found to be a desirable material for mulching, especially if the short fibers are not removed. In the general landscape program on the Station grounds, plants of 15 species were planted near the end of the rainy season in the fall of 1947. The following winter and spring were exceptionally

dry, even for Mayaguez, which normally experiences a well developed winter dry season. All the plants were mulched with a three-inch layer of cocopeat, and not a single plant died because of insufficient moisture, although none of the plants was watered except at planting. The only difficulty encountered with cocopeat for mulching is its light weight. When dry, or nearly dry, a sudden violent rain may cause sufficient run-off to literally float the mulch away. This difficulty can be overcome by using soil conservation measures or otherwise reducing surface water movement, and by applying a light layer of coarse sand or fine gravel on top of the mulch. Cocopeat has the great advantage over many mulching materials of being free of weed seed. Frequently weeds appear after mulching with cocopeat, but it has been found in these cases that the weeds came from seeds already on the surface, which sprouted because of the improved conditions after mulching. Some kinds of mulch, if partially dry, will absorb practically all of the water from a light shower, preventing it from reaching the roots in the soil below. Cocopeat, however, permits rapid penetration of a good part of even a small precipitation. This character is particularly important in regions experiencing chiefly light rains during the dry season.

Cocopeat mixed with heavy soil is particularly beneficial in improving its physical condition. The many porous particles and fibers assist in providing channels for aeration and drainage. On the other hand, sandy soils, which hold little water and nutrients, produce better crops when even small percentages of cocopeat are added because of the very high moisture-holding and nutrient-absorption capacity of this material.

The application of mulch on the surface of a clay subsoil at Mayaguez did not in itself affect the permeability of the clay. Infiltration studies indicated no increase in the rate of soil water intake six months after an application of either one or two inches of cocopeat, but the mulch of cocopeat was able to absorb and hold a tremendous amount of water on the soil until it could soak in (5). The studies show an absorption rate by the cocopeat equivalent to 94 inches per hour, or more than 300 times that of the soil below in these particular trials. It was determined that the water-holding capacity of this cocopeat was 75 percent

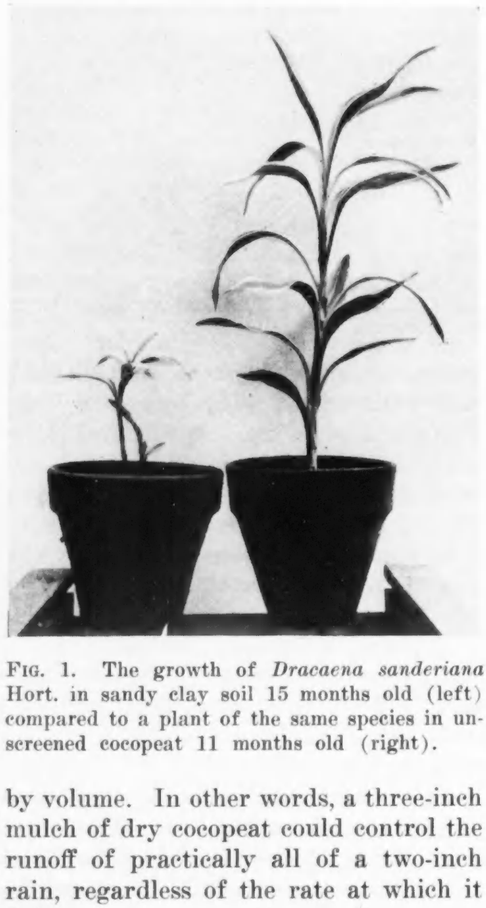

FIG. 1. The growth of *Dracaena sanderiana* Hort. in sandy clay soil 15 months old (left) compared to a plant of the same species in unscreened cocopeat 11 months old (right).

by volume. In other words, a three-inch mulch of dry cocopeat could control the runoff of practically all of a two-inch rain, regardless of the rate at which it falls.

Cocopeat is also useful in propagating seeds and cuttings. Best results have been obtained for these purposes when the peat was mixed with other ingredients. For seed germination equal parts

by volume of cocopeat, sand and compost have given good results. Cuttings can be rooted in a mixture of one part cocopeat and three parts sand. No difference was observed in the rooting of cuttings when the proportion of cocopeat varied from 25 to 75 percent by volume. Adding cocopeat to propagating sand has the advantage, besides reducing the frequency of watering, of making the propagating mixture soft enough so that cuttings can be pushed directly into the mixture without injuring the cut surface.

Unscreened cocopeat, containing short coconut fibers, can be used as a growing medium without other ingredients, as shown in Fig. 1. The danger in this case is from over-watering, but mixing it with sand and loamy soil will overcome this difficulty. Because of its high moisture-holding capacity such a mixture should be useful for those who like to grow plants in the home but tend to forget about regular watering.

Additional experimental work is necessary to establish the place of cocopeat in horticulture. The results so far have been very encouraging. Its use for mulching, soil conditioning and propagation is worthy of trial by all who are interested in trying new horticultural products.

References

1. Cooke, F. C. Investigations on coconuts and coconut products. Straits Settlements & Federated Malay States, Dept. Agr., Gen. Ser. 8, p. 11. 1932.
2. Hageman, R. H. [Unpublished data].
3. Joachim, A. W. R. The manurial value and decomposability of coconut fiber dust. Trop. Agr. (Ceylon) 73: 272–273. 1929.
4. MacMillan, H. F. Tropical planting and gardening. 4th ed. 560 pp. 1935.
5. Smith, R. M. *et al.* [Unpublished data].
6. Wilcox, E. V. Tropical agriculture. 372 pp. 1916.

Utilization Abstract

Margarine. Margarine "is a combination of refined oils, pasteurized and cultured skim milk, salt, and lesser ingredients, processed to desired plasticity, melting point, and flavor". Roughly a third of America's table spread consists of margarine, close to 700 million pounds of which were produced in 1947. The origin of the name lies in the Greek word "margarites", meaning pearl-like.

"Approximately 99 per cent of the oils used are vegetable oils—cottonseed oil, soybean oil, peanut oil, corn oil, and miscellaneous other oils. Of these, cottonseed and soybean oils are the major products used. Last year, for example, cottonseed oil used in margarine manufacture accounted for 48 per cent of the total oils used, and amounted to approximately 223 million pounds of refined oil. This is the oil equivalent of about 3 million acres of cotton.

"Soybean oil accounted for 43 per cent of the margarine oil ingredients, totaling 201 million pounds of oil or the equivalent of about 1,170,000 acres of soybeans. Peanut oil contributed 3 per cent; corn oil, 1 per cent. The animal fats used in 1946 constituted only about 1 per cent, and were mostly beef fat or stearine". (*P. T. Truitt, Chemurgic Digest 7: 15. 1948*).

Grapes and Wine

About 20 per cent of the world's table grapes and 40 per cent of the world's raisins are produced in California, but less than 3 per cent of the wines of the world.

A. J. WINKLER

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The grapevine has furnished man with food and drink from the dawn of civilization. Noah planted a vineyard. Grape and wine production were figured in the mosaics of the earliest Egyptian dynasties. Later the Roman statesmen and naturalists—Cato, the Plinys, and Columella—wrote of the grape and of wines. They described many varieties, listed numerous types of wine, and gave directions for the training of young vines and the making of wine.

Grapes

Grape production, as an industry, appears to have started around the southern end of the Caspian Sea. From there it spread to other parts of Asia and then to Europe. The Phoenicians carried it to France about 600 B.C., and the Romans planted grapes on the Rhine. At about the same time grape culture was moving around the Mediterranean to North Africa. As the Europeans colonized new lands, the grape was always among the plants taken along. Today it is cultivated on all the continents and islands of the world where climatic conditions are favorable for its production.

Species. One species, *Vitis vinifera* L., supplied all of the grapes that were grown by civilized man for centuries. It is the grape mentioned in the Bible; the grape of the myths and of poets; the grape from which the wines and raisins of world commerce and most of the table grapes are produced. It is the Old World grape, the European grape, and more recently in America the California grape.

Not until eastern North America was colonized was there need for other species. Here the insect phylloxera, *Dactylospheara vitifoliae* Shimer, and several cryptogamic diseases destroyed the vines of *Vitis vinifera.* Fortunately, North America was blessed with many native species of *Vitis.* The species of the Midwest and East, which had lived with the phylloxera and diseases, were resistant to their attack. With the failure of their vinifera vines, the American colonists turned to the native *Vitis* species for grapes. Selections of *Vitis Labrusca* L., or hybrids of it with vinifera and other American species, formed the basis of a new and different grape industry in that part of the United States. These are true grapes, but they differ greatly from vinifera in both morphology and in the flavor of their fruit. Many of these are so-called "slip skins" and have a pronounced aromatic or "foxy" flavor.

In the southern part of the United States east of Texas, varieties of *Vitis rotundifolia* Michaux are cultivated. These are muscadines, not true grapes. The berries are borne singly or in very

small clusters, mature irregularly, and drop when ripe. Nevertheless, they are important, since they are very hardy under hot and humid conditions.

Not content with the best grapes in the world and in the interest of science, Europeans introduced the American grapes when these became available. With these plants, unbeknown at the time, they unwittingly took the insect phylloxera and the diseases downy mildew, *Plasmopara viticola* Berk. and Curt., and black rot, *Guignarda Bidwellii* Ellis, to Europe. In the course of little more than two decades following its introduction into France, phylloxera destroyed most of their vineyards. To reconstitute these vineyards, French viticulturists came to America in search of rootstocks that were resistant to this organism. They were successful, and soon the decadent vineyards of Europe flourished again, but on rootstocks of American species or hybrids. Among the rootstocks are selections of *V. rupestris* Scheele, *V. riparia* Michaux, and *V. Champini* Planchon, hybrids of these, and *V. cinerea* Engelman, *V. Berlandieri* P., *V. Candicans* Eng., *V. Solonis* Berol. and Planch. and *V. Monticola* Buc., or hybrids of vinifera varieties with certain of the foregoing species.

Along with their efforts to control phylloxera Europeans attempted to produce vines that were also resistant to various diseases by hybridizing *Vitis vinifera* varieties with American species, such as *V. aestivales* Michaux, *V. riparia, V. Lincecumii* Buckley and *V. rupestris.* These hybrid varieties are neither "slip skins" nor foxy in flavor. They are the so-called "producteurs directs" which are grown to some extent in certain parts of Europe because of their resistance to fungus diseases.

Kinds of Grapes. On the basis of use, grapes are grouped as follows: (*a*) wine grapes, (*b*) raisin grapes, (*c*) table grapes, (*d*) sweet juice grapes, and (*e*) canning grapes. The mature fruit of all named grape varieties—about 8,000—will ferment into a kind of wine when it is crushed, and most of them can be dried or eaten fresh. Only a limited number of varieties, however, produce standard or higher quality wines. The raisins of commerce are produced mainly from three varieties, less than a dozen varieties are grown extensively as table grapes, the bulk of the sweet juice produced in America is of one variety, and only one variety is used for canning.

A wine grape may be defined as a variety known to be capable of producing an acceptable wine in some locality. Table (or dry) wines require grapes of high acidity and moderate sugar content, while dessert (or sweet) wines are more palatable if the grapes are high in sugar and moderately low in acidity. In addition to the constituent balances just stated, high quality wines, which are outstanding in bouquet, flavor and general balance, require that the grapes utilized in their production possess special characteristics, such as those of the White Riesling, Semillon, Cabernet Sauvignon, Tinta Madeira and similar varieties when they are grown under favorable climatic conditions.

Raisin grapes are grapes that produce an acceptable dried product. Raisins, therefore, are dried grapes; yet different varieties and different methods of drying yield very unlike products. To be a good variety for the production of raisins, the dried product must possess: (*a*) a soft texture, (*b*) little tendency to become sticky, (*c*) seedlessness, (*d*) a marked, pleasing flavor, and (*e*) large or very small size. Only the products of the Thompson Seedless, Muscat of Alexandria and Black Corinth meet most of these requirements.

Grapes used fresh, either for food or for decoration, are generally called "table grapes." They must be attractive in appearance and pleasing to the palate. Large size, brilliant color and unusual form are generally appreciated. Where these grapes must be shipped long distances to reach the markets, or when they are to be stored for a considerable period, firmness of pulp, toughness of skin and adherence to the pedicel become very important. These qualities are possessed in marked degree by the table varieties, such as the Flame Tokay, Emperor, Malaga, Red Malaga (Molinera), Almeria (Ohanez) and Ribier (Alphonse Lavallee), all of which are grown in California, South Africa, Australia, Argentina and elsewhere. The Thompson Seedless (Sultanina) owes its popularity mainly to its seedlessness.

Sweet juice grapes are those varieties of which the juice produces an acceptable beverage when it is preserved by pasteurization or germproof filtration. The juice must retain the natural fresh-grape flavor. In America pasteurization alone has been employed to preserve grape juice. Most vinifera varieties, including the strong-flavored Muscats, when pasteurized by the usual methods,

THE PRINCIPAL GRAPE-PRODUCING COUNTRIES OF THE WORLD, WITH THE APPROXIMATE ACREAGE AND AVERAGE ANNUAL PRODUCTION OF WINES, TABLE GRAPES AND RAISINS FOR EACH DURING THE PAST FIVE YEARS

	Area in grapes (thousands of acres)	*Wines (millions of gallons)*	*Table grapes (thousands of tons)*	*Raisins (thousands of tons)*
Austria	83	22	......	......
Bulgaria	379	53	70	......
Czechoslovakia	43	14	......	......
France	3,340	895	145	......
Germany	153	45	......	......
Greece	548	68	75	95*
Hungary	598	125	20	......
Italy	3,160	880	140	10
Portugal	860	260	......	......
Roumania	520	220	350	......
Spain	3,380	495	190	11
Switzerland	32	20	2	......
Yugoslavia	550	125	......	......
Cyprus	133	2	15	4
Syria	121	2	10	1
Turkey	1,090	15*	80	60
U. S. S. R.†	870	130	275	30
Algeria	840	490	18	......
Tunisia	67	14	2	......
Union of South Africa	97	50	......	11
Argentina	430	210	250	5
Brazil	84	20	......	......
Chile	247	80	......	2
Australia	128	21	15	82
United States—total	670	120	630	260
United States—California	490	110	500	260

Sources of data: International Yearbook of Agriculture and Bulletin Office International du Vin Nos. 201 and 202.

* On basis of prewar records and minor changes in acreage figures appear low.

† In view of new planting and acreage shifts during World War II, all figures appear low.

lose their fresh flavor and acquire an unpleasant cooked taste. The strong-flavored American varieties, particularly the Concord, are less affected by pasteurization. This fact largely accounts for the general use of the Concord for juice in the United States—of course, some people like these flavors. In central Europe a thriving industry was developed prior to World War II using close filtration for sterilization. There the good vinifera varieties, such as the White Riesling and Chasselas doré, that had won renown for wine production, were used for juice.

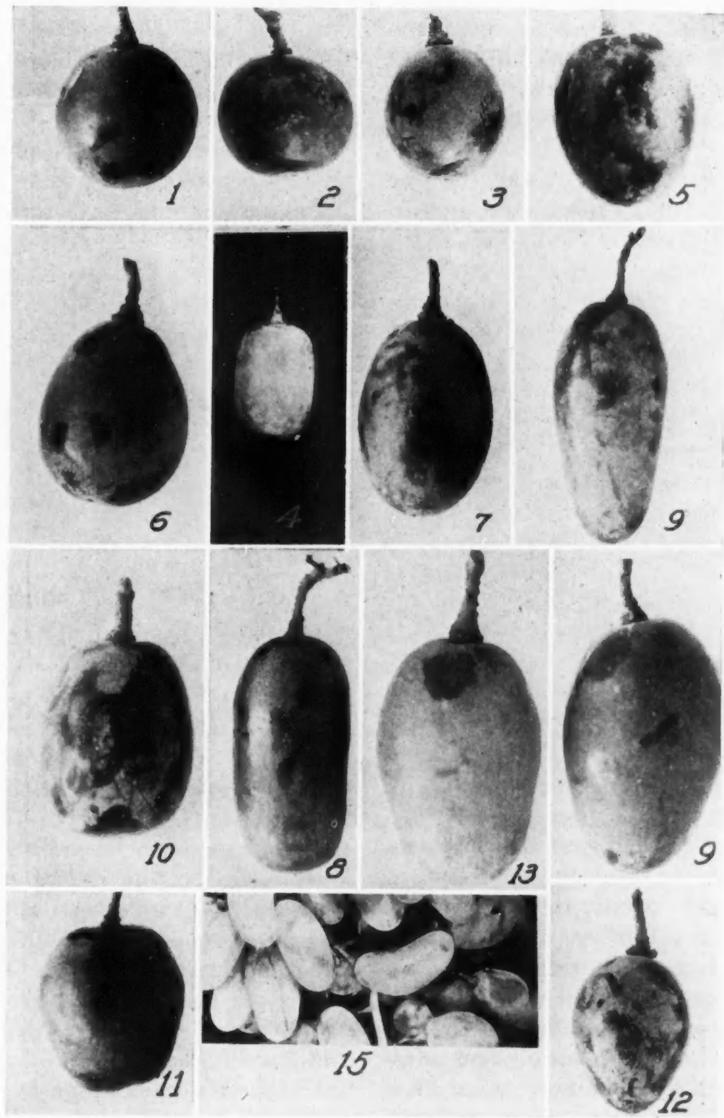


FIG. 1. Grape berry shapes: 1, spherical; 2, oblate; 3, ellipsoidal; 4, cylindrical; 5, ovoid; 6, obovoid; 7, ellipsoidal elongated; 8, cylindroidal elongated; 9, ovoid elongated; 10, obovoid elongated; 11, ovoid truncated; 12, ovoid pointed; 13, fusiform; 15, falcoid (*Hilgardia* **11** (*6*)).

Grapes are canned largely in combi-

nation with other fruits in the production of fruit salad and fruit cocktail. Only seedless sorts are used, usually the Thompson Seedless.

Extent and Distribution of Industry. The principal grape-producing countries of the world, together with the acreage planted to grapes in each, with approximate yields, are listed in the accompanying table.

Owing to the ravages of war, the production in Europe suffered severely during the past decade. Nevertheless, the first ten countries in the order of importance in the production of wine are: France, Italy, Spain, Algeria, Portugal, Roumania, Argentine, Russia, Yugoslavia and Hungary. The United States produces less than 3 per cent of the wines of the world.

The production of table grapes and raisins was increased during the war years. The United States, or more correctly California, has retained first place in the production of both table grapes and raisins. Statistics indicate that roughly 20 per cent of the world's table grapes and 40 per cent of the world's raisins are produced in California.

Climate. Vinifera grapes require long, warm to hot, dry summers and cool winters for their best development. Humid summers favor the development of diseases that attack the fruit, while severe winter conditions (0° F or below) will destroy the vine if it is not protected. Spring frosts after the vines start growth kill the shoots and clusters. Rain during winter to supply soil moisture is desirable, but summer rains make the control of diseases more difficult. Rains of considerable duration during the ripening and harvest periods may cause rotting of the fruit. Where raisins are to be produced by natural sun-drying, as is the custom in California, a month of clear, warm, rainless weather after the grapes are mature is essential.

Varieties possessing the characteristics of *Vitis Labrusca* will withstand humid summers and colder winters better than those of vinifera. In fact, they may do better where summer rains of short duration are the rule. Varieties of *Vitis rotundifolia* thrive in very warm, humid regions of the southeastern states of the United States.

The limitation of grape production to the temperate zone is due to climate. As climate limits grape-growing to a broad zone, so it also limits the highest development of individual varieties to localized areas within this zone. For example, the Flame Tokay, a table grape, attains its most acceptable development in California in the warm, dry, ten-square-mile area at Lodi, and the Emperor, table grape, is restricted to a hot, dry district in eastern Tulare and Fresno counties; while the combination of the particular climate of certain regions of Europe with the qualities of White Riesling, the Pinot noir, Cabernet Sauvignon, and Chardonnay have made possible some of the greatest table wines of the world.

Table wines are better when the suitable varieties are grown in cool regions. Under relatively cool conditions ripening proceeds slowly. This is favorable for the production of high quality, since it fosters the retention of a high degree of acidity, low pH and the development of good color. With most table-wine varieties, these conditions bring the aroma and flavoring constituents of grapes and the precursors of the bouquet and flavoring substances of the wines to the highest degree of perfection in the mature fruit.

An abundance of heat is ideal for production of the grape varieties from which dessert wines such as port, Muscatel and sherry are derived. Large summations of heat, especially just before and during ripening, favor a high ratio of sugar to acid in the mature fruit,

which, with the development of the other constituents of the fruit under such conditions, make for smoothness and mellowness in the aged product. The effect of the heat on the aroma and flavor is less objectionable than with table wines.

Temperature is by far the most important factor of climate. In addition to its effects indicated above, temperature governs the time elapsing from full bloom to a given degree of maturity. For example, 2,000° days (a degree-day as used here is 1° above 50° F for 24 hours) will bring the fruit of Thompson Seedless from full bloom to 18° Balling (per cent total soluble solids). Other varieties require more or less heat, depending on whether or not they are early or late maturing. Although this total summation of heat may be used to indicate degree of maturity, it does not indicate palatability. This is influenced more by the summation of heat during the ripening period. With cool weather during this period, the fruit will be higher in acid and taste sour, while with hot weather it will be lower in acid and taste sweet.

FIG. 2. Vineyard of the coastal area of California (for vineyards of the interior valleys of California see Fig. 8). (*Courtesy of the Wine Institute.*)

Vineyard Soils. Grapes are adapted to a wide range of soils. Grape growers often express a preference for certain soil types, yet when a survey is made of soils used for grapes in the many different localities, it is found that grapes grow on soils ranging from blow sands to clay loams, from shallow to very deep soils, highly calcareous to noncalcareous soils, and from low to high fertility. The extremes in all these variations are less desirable, and poorly drained soils or soils containing excess salts are to be avoided. The deeper and more fertile soils produce the highest tonnages; they are preferred for raisins, common wine grapes and some table grapes. *A priori*

information would appear to indicate that certain of the better wine grapes and certain table-grape varieties attain a higher quality when grown on soils of limited fertility and depth.

Establishing the Vineyard. Commercial grape varieties are propagated asexually. This is accomplished by utilizing cuttings or making grafts which are grown for one year in the nursery. The cuttings may be of fruiting varieties or of rootstocks. The grafts consist of a segment of a stem of a fruiting variety placed on a rootstock cutting. In Europe grafts are regularly used to establish vineyards where root-destroying organisms are present. In California grafts and rooted rootstock cuttings are employed. The latter are field budded to the desired fruiting variety in late summer after they are planted in the vineyard.

For convenience in planting, the roots of the rooted vines or grafts are shortened to three or four inches. These are planted at the same depth they stood in the nursery. The union of grafted or budded vines must be above the soil so that there is no scion root production. Planting distances vary widely in the different countries of the world. In Europe the distances range from 3×3 feet to 4×7 feet, while in California, where cultivation is largely mechanized, the widest spacing is employed; the vines are planted 7×7, 8×8 and 8×10 in the coastal areas, 10×10 and 8×12 feet in the interior valleys. Intermediate planting distances are used in Australia, South Africa and South America.

Training consists in the development of a vine of desirable form. It is accomplished by pruning and the tying of the young vine and its growth to the support. Vinifera varieties are trained to two general forms, namely, headed and cordon vines (Fig. 3). In the former there is a straight, vertical trunk or stem of the desired height, with arms radiating out from its top to form the head, while with the latter the trunk is much elongated, either vertically or horizontally. The most widely used cordon is the bilateral, in which the trunk rises vertically to the desired height where it is divided into the two branches which extend horizontally in opposite directions along the row. Arms arise on the upper side of the horizontal parts of the trunk. Head training is universal for wine and raisin grapes and some table varieties. The bilateral cordon is useful for certain large-clustered table grapes, especially Ribier and Red Malaga. These are the commercial systems, but minor variations from them occur in some producing areas, and it must be remembered that the vine is readily trained to walls, pergolas, and arbors.

The common supports for all head-trained, spur-pruned vines are stakes, while the cordon-trained, spur-pruned

FIG. 3. Systems of training and pruning: (*Left*) Head-training with spur pruning. (*Center*) Cordon-training with spur pruning. (*Right*) Head-training with cane (or long) pruning.

and head-trained, cane-pruned vines are usually supported with trellises. The most generally used trellis has two wires, the bottom wire being at 34 and the top wire at 48 inches above the ground. The stakes and wire supports are usually 2×2 inch split, durable wood, such as redwood in California, of desirable length: four, six or eight feet, according to the variety and the country.

Pruning. Pruning is the most important single vineyard operation. It is usually the sole means of regulating crop with wine and raisin varieties, and thus it largely determines not only the quality of the fruit but also the quality of the wood for the next year. From 90 to 95 per cent or more of the year's growth of shoots or canes is removed at the annual pruning. At pruning, spurs or fruit canes, or both, are retained. Spurs are used for the varieties of which the basal buds, near the point of origin of the canes, are fruitful, while fruit canes are necessary where the buds near the basal end of the cane are unfruitful, and with varieties that produce very small clusters in which many clusters are required to produce a full crop. Spurs of one, two, three or four buds in length are used according to the fruiting habit of the variety and the size of the individual cane from which the spur is retained. Likewise, canes vary in length from eight to 12 or 15 buds. The number of spurs or canes retained on a vine should vary with its size and the vigor of the year's growth. In cane pruning a renewal spur of 2 buds is retained for each fruit cane for the production of fruiting wood for the next year and to aid in maintaining the form of the vine. The canes are removed after they have produced a crop. Variations from the above procedure are encountered, but they are largely adaptations to local conditions and not in principle.

The grape starts growth late in spring, not until the mean daily temperature reaches approximately 50° F. Growth is rapid, reaching a peak in early summer; then it slows down so that little further shoot elongation occurs after the fruit begins to ripen. The leaves, however, continue to function until the end of the season. Fruit-bud differentiation begins with the accumulation of carbohydrates in the shoots soon after length growth slows down in summer. The cluster primordia develop to the growing points for the individual flowers by leaf fall. Thus, the number of flowers to be produced and the shape of the clusters are largely determined in the year prior to that in which the fruit is produced. The parts of the flowers develop in the spring after growth starts. Grapes bloom six to eight weeks after leafing out, depending on seasonal conditions.

Set of the Berries. In the normal setting of the fruit of the grape, pollination is followed by fertilization and this in turn by seed development. Along with this type of fruit setting there are a considerable number of varieties in which part or most of the normal mechanism of fruit setting fails to function. As a result, there is wide variation in berry size, berry shape and uniformity of size and shape which is correlated with the type of fruit setting of the variety. Four types of fruiting or fruit setting will be mentioned. Although these variations are continuous from one type to the other, the set of fruit within an individual variety is relatively constant.

The most common type of setting is that in which normal seed development occurs. In such varieties each carpel has one, two or more seeds, and the berries are relatively uniform in size and shape. They are round, oval or fusiform, according to the variety. In other varieties only one or two seeds develop to a berry. With much elongated ber-

ries, the presence of a single or two adjacent seeds may cause the berries to be facoid in shape (see 15, Fig. 1).

In a second type most of the seeds produced are empty. Empty seeds result from embryo abortion after the seed is well advanced in its development. Some varieties produce less than three per cent of viable seeds. As a rule, the berries of such varieties are non-uniform in both size and shape; that is, the variation resulting from the stimulus of fertilization and the different stages of development attained by the embryo prior to aborting is marked.

The other two types result in seedless fruit. There are two different types of seedlessness among commercial grape varieties. In the one type fertilization takes place, but abortion occurs sufficiently early so that only rudiments of seeds are present. These are thin-walled or often hardly more than enlargements of the vascular strands. This type of fruit setting is common to a number of important varieties. The best known is the Thompson Seedless which produces two thirds of the world's raisins and is used extensively as a table grape in America.

In still another type the fruit setting is by stimulative parthenocarpy. In this type the berries are very small and round, with no trace of seeds. Seedlessness and small size, however, have been important factors in making the Black Corinth of great commercial importance. The variety supplies the Zante or dried currants of commerce.

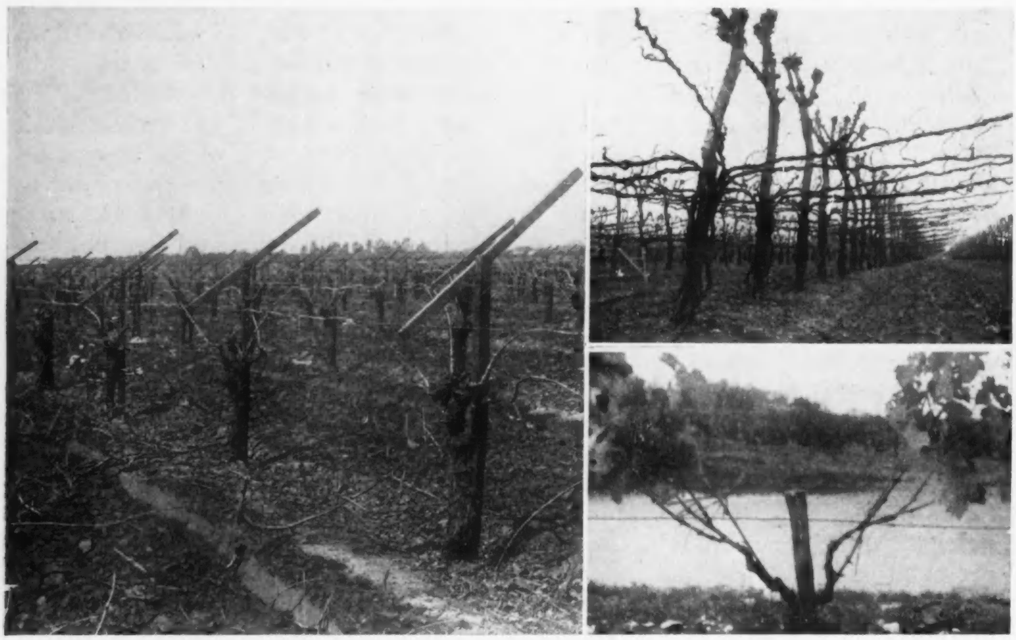


FIG. 4. Supports for vines: (*Left*) Sloping top, four-wire trellis, California. (*Upper right*) Trees for vine supports, Italy. (*Lower right*) One-wire trellis, France. (See Figs. 2 and 5 for simple stake supports.)

Thinning Table Grapes. Not all varieties of grapes set equally well. Some varieties set clusters that are too compact; the clusters of others are well filled; those of others are loose to the point of being straggly; and still others set shot (parthenocarpic) berries along with the normal berries.

As an aid in correcting the objection-

able features of the setting of certain varieties of table grapes, several methods of fruit thinning have been developed. When an overabundance of berries makes the clusters too compact or when overlarge cluster parts interfere with proper coloring and maturing, berry thinning will improve quality. As used in California, berry thinning consists with no removal of leaves improves the carbohydrate nutrition of those retained. As a result, a better set of normal berries may be secured. Flower-cluster thinning is useful on varieties that have loose or straggly clusters, or which tend to set shot berries with the usual pruning. The increase in the set of normal berries appears to affect sufficiently the

FIG. 5. Tractor-drawn disk with two Molley plows attached at opposite sides to back of disk, and with two Kirpy plows, one right and one left hand, attached by chains to back corners of disk. This combination of implements with three men effectively cultivates 20 acres of vineyard per day. (*Cal. Agr. Exp. Sta. Circ.* 116.)

in removing parts of clusters, usually by cutting the rachis, to leave only the desired number of berries, while in other areas individual berries are removed. When the thinning is done soon after the set of the berries, a marked increase in berry size is usually obtained.

In another method flower clusters are removed soon after they emerge, which nutrition of the flowers that are not fertilized to reduce the setting of shot berries. For best results the vines should be pruned to retain more buds and then thinned as soon as possible after the flower clusters appear.

A third method, cluster thinning, consists in the removal of entire clusters soon after the berries have set. By leav-

ing enough fruiting wood at pruning to produce a full crop in all years and then reducing the overload in years of good set by cluster thinning, larger crops of high-quality fruit can be produced every year. By improving the nutrition of the fruit that is retained, cluster thinning enhances the size and color of the berries and tends to advance maturity.

Girdling. This operation, which is also called "ringing", consists in removing a complete ring of bark, $\frac{3}{16}$ to $\frac{1}{4}$ inch wide, from the trunk or a cane below the fruit which it is intended to affect. As a result, carbohydrates can not move downward, through the phloem, and an accumulation occurs above the girdle.

When the girdle is open and effective during bloom, it increases the set of seedless berries; when it is open during the period of rapid growth of seedless berries, it increases the size of berry; and when it is open during the early part of the ripening period of seeded varieties, the coloring and ripening may be accelerated. Girdling is a regular operation for improving the set of Black Corinth wherever it is grown and for increasing the size of berry and firmness of Thompson Seedless and improving the coloring of Ribier and Red Malaga in California.

Cultivation. In unirrigated vineyards the only water available to the vines is the underground water. In areas of rainless summers, as in California, or where periods of drought are of common occurrence, the weeds are destroyed before they rob the vines of appreciable amounts of soil moisture. A winter covercrop or growth of native plants is usually encouraged. On rolling soils and hillsides this winter cover is of great value in preventing erosion. The winter cover is destroyed at the end of the rainy season or at the spring cleanup (Fig. 5). Cultivation should be repeated only often enough to destroy or prevent further weed growth. Cultivation conserves soil moisture only by eliminating weeds and not by virtue of loosening or pulverizing the soil. In the absence of perennial noxious weeds, it is discontinued as soon as the surface soil becomes too dry for seed germination. Shallow cultivation is favored in most vineyard areas.

In irrigated vineyards the matter of weed competition is of less importance. Such vineyards are usually cleaned up in spring and kept free of weeds during the period of rapid vine growth in order to eliminate weed competition for soil nutrients. When ample soil moisture is available, weed growth after midsummer is controlled only to prevent undue interference with the various vineyard operations. For example, in many table-grape vineyards of California that are free of noxious weeds, the native grasses are permitted to grow. It appears that the readily available supply of certain elements is utilized by the grass and vine to such an extent that vine growth is checked, and, as a result, maturing is advanced and the grapes may be of a firmer texture, have a tougher skin, have better matured stems, and be more brilliant in color.

Irrigation. Vinifera grapes do best in long, warm-to-hot, dry summers; however, where the rainfall is insufficient to meet the water requirements of the vine, the deficiency in soil moisture must be made up by irrigation. In the absence of sufficient rain, the soil is wetted as deep as the roots penetrate during the late fall, winter or early spring. After growth starts, the vines are allowed to almost exhaust the available water in the soil area containing most of the roots, then water is applied to rewet the soil. This practice should be repeated as required until the grapes are nearly ripe; the amount and frequency of the applications of water being determined by the texture and depth of the soil,

climatic conditions, type of grapes grown and cultural methods. In very hot regions or with early-maturing sorts, one or more irrigations may be required after harvest to maintain vine growth so that the wood will mature normally.

Insects and Diseases. The grapevine and its fruit are seriously attacked by a number of insects and diseases. In the arid countries or regions there are fewer pests. In California and other arid rigions the principal insects attacking the vine are the phylloxera, *Dactylosphaera vitifoliae* Shimer, a root louse, and the root knot nematode, *Heterodera marioni* Cornu, which are combated by using resistant rootstocks. The grape leafhopper, *Erythroneura elegantula* Osb., which is controlled with DDT; the grape root worm, *Adoxus obscurus* Li.; the grape leaf roller, *Desmia funeralis* Hübner; and the red spiders, *Tetranychus pacificus* McG., which can apparently be controlled by some of the new organic phosphate insecticides either as dusts or sprays, are also important. In more humid regions there are in addition to the above the berry moths, *Polychrosis botrana* Schiff and *Clysia ambiguella* Hübner, and various beetles and caterpillars which may be controlled with arsenicals.

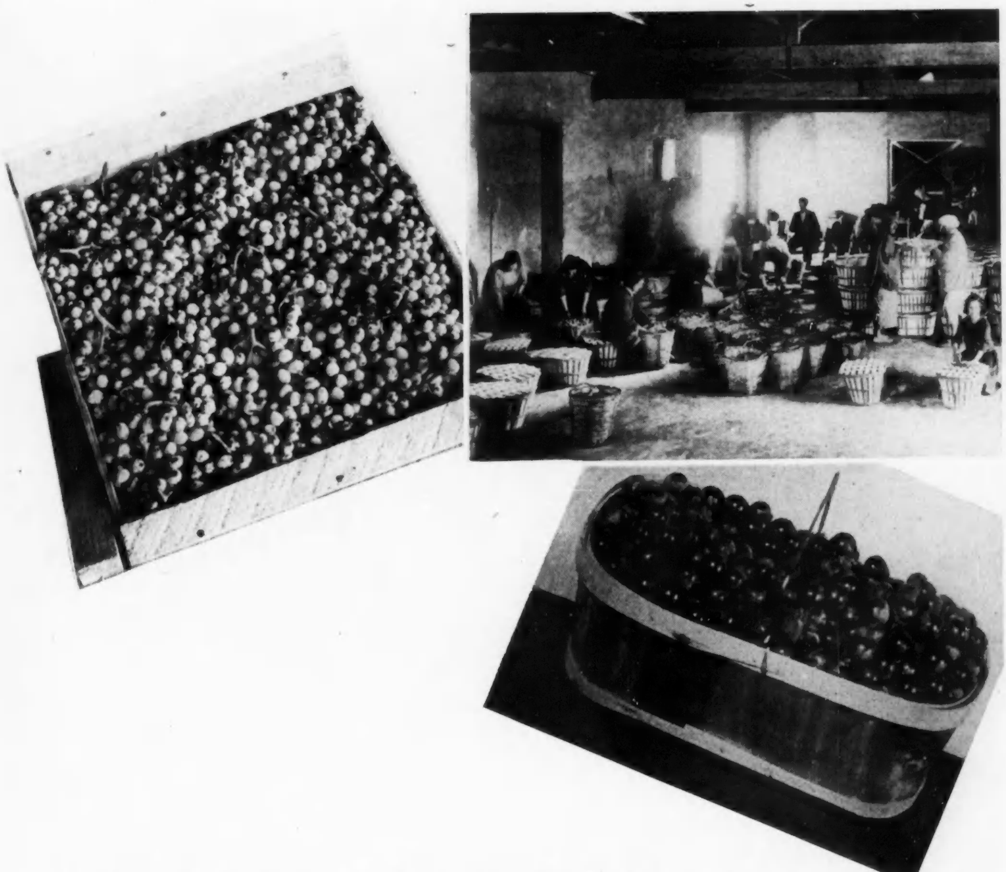


FIG. 6. Packed containers of table grapes: (*Left*) "Stems up" pack in lug box, California. (*Upper right*) Large slat baskets, Algeria. (*Lower right*) Climax basket, eastern United States. (*Last from U. S. Dept. Agr., Farm. Bull. 1558.*)

Diseases affecting the grape under arid conditions are powdery mildew, *Uncinula necatar* Schw., prevented by dusting elemental sulfur on all green parts of the vine; black knot, *Phytomonas tumefaciens* Smith and Towne; Pierce's disease (in California), a virus, control unknown; and black measles, cause unknown but controlled by sodium arsenite spray while the vines are completely dormant. Under humid conditions the grape is also attacked by black rot, *Guignarda Bidwelli* Ellis; anthracnose, *Gloeosporium ampelophagum* Pass.; downy mildew, *Plasmopara viticola* B. and C., which are controlled with Bordeaux sprays; *Cryptosporella viticola* Reddick, which is controlled by sodium arsenite; and numerous minor diseases.

Harvesting. A grape is ripe when it has reached the stage best suited for the use to which it is to be put. The ripe stage is the condition that results when the changes in the several components that make up quality have proceeded to a point where their combined effect on the quality of a given variety is the nearest possible approach to an ideal for a given purpose. The ripe stage is not absolute nor does it represent the end product in the changes that are proceeding in the berries. For example, for

FIG. 7. Picking Thompson Seedless grapes directly onto trays for sun drying between the vine rows.

one purpose a grape of moderate sugar and relatively high acid content may be best, while for another purpose high sugar content and low acidity may be most desirable.

Table grapes are harvested when they are sufficiently mature to be attractive and palatable. Above the minimum sugar content for the variety the degree of satisfaction with which grapes may be eaten depends on the ratio of sugar to acid.

The containers in which table grapes are moved to market and the methods which reduces their deterioration markedly. The benefits of treatment with sulfur dioxide are: suppression of the growth of molds and other decay-causing organisms, reduction in the respiration of the fruit and retention of the green coloring in the stems. In the shipment of grapes the best method of applying the sulfur dioxide is by displacing the air of the standard refrigerator car with sulfur dioxide diluted with air to a concentration of approximately 1 per cent by volume. Immediately after the treatment the ventilators

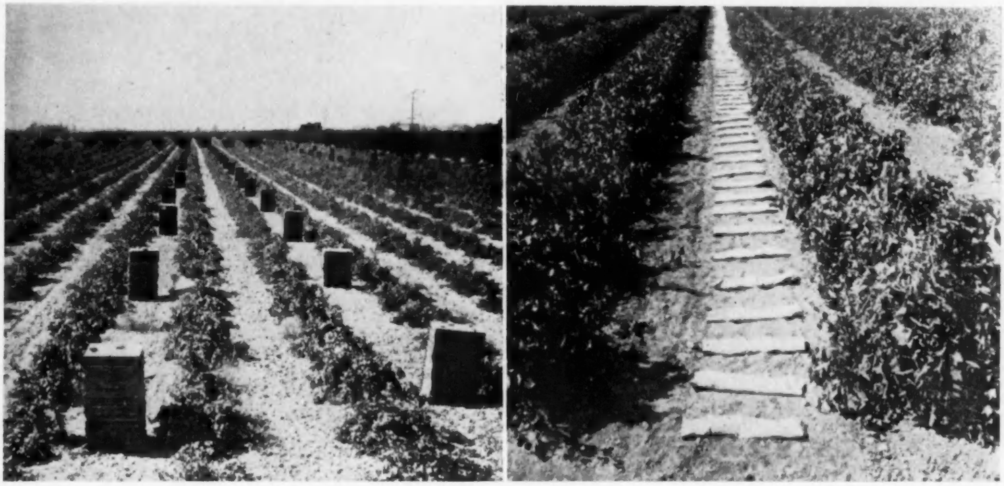


FIG. 8. Finishing the drying of raisins: (*Left*) Stacked wooden trays. (*Right*) Rolled paper trays.

of packing the fruit in the containers vary greatly from country to country (Fig. 6). The least handling consistent with thorough trimming, to remove injured berries, and with efficient packing is imperative. The sooner the grapes are cooled after being removed from the vine, the better will be their quality when they reach the market. Deterioration is very rapid at high temperatures.

When grapes are to be shipped long distances or held in storage (at 31° F) for prolonged periods, it has been found advisable to supplement the low temperature by treating the grapes with 15 to 20 parts per million of sulfur dioxide and doors of the car are closed, and the grapes absorb the sulfur dioxide. Grapes in cold storage are treated at seven- and ten-day intervals by releasing sulfur dioxide into the air (about ¼ per cent) as it enters the storage room. After 20 to 25 minutes the air with sulfur dioxide is blown out of the storage room.

When raisins are made by the natural sun-drying process, as in California, the riper the grapes the better the raisins and the higher the yield. Thus, the grapes are left on the vines as long as possible and still having a reasonable safe period for drying. The grapes are picked from the vines and spread evenly

on wooden or paper trays without pretreatment of any kind (Fig. 7). When the berries on the upper side of the clusters have shriveled and turned brown, the grapes are turned upside down onto another tray. In sun drying the slow oxidation that proceeds in the berries is instrumental in the development of the typical raisin flavor. Wooden trays are stacked and paper trays rolled when the raisins are three fourths dry (Fig. 8). In most of the other raisin-producing countries the drying weather is less favorable, and the grapes are pretreated with or dipped into weak caustic or carbonate solutions with or without emulsified olive oil to hasten drying and to produce a lighter colored product. The dips vary in both composition and concentration, but their function is to render the skins of the grapes more permeable, either by checking or by removing the bloom, or both. A limited tonnage of grapes is dehydrated. Grapes to be dehydrated are usually dipped, to produce small checks or cracks in their skin which facilitate water loss, and treated with sulfur dioxide to produce a translucent, golden-colored product. Dehydrated grapes do not possess a "raisin" flavor.

The time for picking wine grapes is influenced by the kind of wine to be made. Grapes for table wines, except for the natural sweet, should be of high acidity and moderate sugar content. Such grapes are usually harvested after they test 18° Balling but before they reach 23°. For dessert wines the grapes should be high in sugar and of moderate acidity. Grapes for sweet dessert wines are allowed to attain as high a sugar content as is possible without raisining—usually 24° Balling or more.

Wines

Wine is the beverage resulting from the partial or complete fermentation of the juice of sound, ripe grapes under controlled conditions.

Man, no doubt, ate the fruit of the vine long before he became acquainted with fermentation and its possibilities. Yet, the records of the early spread in grape production show that it was largely of varieties adapted for wine and not for eating fresh. This would indicate that man has long been familiar with wine.

Kinds of Wine. The great variety of grapes used, differences in the environmental conditions under which the grapes are grown, differences in the degree of completeness of the fermentation, and differences in the cellar treatment has resulted in the production of many kinds of wines in various parts of the world.

Despite the large number of individual kinds, wines may be grouped into two classes, namely, those that derive their alcohol entirely from their own fermentation and those to which grape spirits (alcohol) are added in addition to that derived from their own fermentation.

The wines of the first group may be dry or sweet, white or red, still or sparkling. These wines have been called "dry wines", "natural wines", "light wines", *etc.*, but none of these terms covers accurately all of the kinds included—some of them are quite sweet and others are decidedly heavy (alcoholic). All of these wines, however, are intended for consumption primarily with food; hence it appears that they may be more correctly termed "table wines". The wines of European countries are predominantly of this group—90 per cent or more.

The wines of the second group again may be sweet or dry, white or red, but they are always still. These wines may best be called "dessert" and "appetizer" wines, since this again indicates their most common use. More than two thirds of the wine produced in the United States belongs to this group.

Beyond these large groups, wines are

FIG. 9. Picking wine grapes: (*Upper*) In Algeria. (*Lower*) In California.

segregated according to the country of origin and the type. Wines are of a single type when their general and special characteristics show a pronounced similarity. In the case of "table wines", for example, if the term "type" is to have significance, a given type may include only wines of a single variety of pronounced character, a principal variety of pronounced character and several minor supplementary varieties, or several varieties of distinct character that are produced under special environmental conditions. In each case the vinification procedure must be such that will bring the potential qualities of the mature grapes to their full development in the aged wine. Most "dessert" and "appetizer" wine types, on the contrary, are usually blends within and between years, but again they must be of a limited producing area and of standardized vinification practice. Some varietal wines, such as the Cabernets and Muscatels, because of their very pronounced aroma and flavor, may be produced under conditions that vary considerably and still retain their type identity.

Wine Types. Each of the countries growing wines has one or more types. Most of these are primarily of local interest; some, however, have gained recognition beyond the borders of the producing areas, and others have won world renown. Only a few types will be mentioned for purposes of illustration.

Recognized white table wine types are: Riesling of Germany; Tokai of Hungary; Chablis, Champagne, Sauternes and White Burgundy of France; and Chardonnay, Johannisberg Riesling, Sauvignon blanc, Semillon of California.

Red table wines of general interest are: Burgundy and Claret of France; Chianti and Barolo of Italy; Cabernet, Pinot noir and Zinfandel of California.

Dessert wine types are less numerous. The better known are: port, angelica, muscatel and the sweet sherries.

The appetizer wines are the dry sherries and vermouth.

Fermentation. Transformation of the sugars in the juice of grapes to alcohol and carbon dioxide by yeasts under favorable conditions is called "fermentation". It is brought about by enzymes produced by yeasts. Other organisms, such as molds and bacteria, may also bring about the fermentation of sugars, but they impart undesirable flavors to the product and are incapable of producing a high percentage of alcohol. Yeasts, too, vary in their ability to ferment; in the efficiency of the fermentation; and in the character, quantity and and type of the by-products produced. The wine yeasts, *Saccharomyces ellipsoideus* strains, ferment the must or juice free of sugar and produce a desirable vinous flavor.

The use of selected yeasts is a regular practice in many wine-producing areas. This is particularly true when weather conditions during the harvest are unfavorable and when sulfur dioxide is employed to check the activities of undesirable organisms. The use of a pure culture of yeast (1 to 3 per cent of the total) together with sulfur dioxide (50 to 100 p.p.m.) results in a fermentation that begins promptly, proceeds vigorously and goes to completion. Although some strains of wine yeast may have some inherent flavor-producing capacity, the quality and character of the wine is determined largely by the grape variety used, its delicacy and richness being governed by the environment in which the grapes are grown.

In the fermentation of grape must, the principal products are alcohol and carbon dioxide. The quantity of these as well as the kind and concentration of the by-products will vary with the strain of yeast used and with the composition, temperature and extent of the aeration

of the must. The overall equation for the fermentation of grape must is as follows:

$C_6H_{12}O_6$	$\rightarrow$	$2C_2H_5OH$	+	$2CO_2$
dextrose or levulose		ethyl alcohol		carbon dioxide gas

The process, however, is much more complex than this equation indicates. The fermentation of grape sugars proceeds in a series of well-defined stages, involving the formation of a number of intermediate products and the interaction of several enzyme systems. Acetaldehyde, glycerin, 2,3-butylene glycol, lactic acid and acetic acid are regular products of alcoholic fermentation. Other products, such as succinic acid and higher alcohols, which are produced only in small amount but which may be of considerable importance, arise when there is over-aeration during fermentation or as a result of the action of yeasts on substances other than sugars.

The above equation indicates a theoretical yield of alcohol of 51.1 per cent of the weight of the sugar used. In practice, however, the yield of alcohol approximates only 47 per cent, the remainder of the sugar being used by the yeast for growth and respiration or converted into other products.

In the production of white table wines only the free-run juice is fermented. After crushing, the juice may be permitted to stand on the skins for a time to absorb more of the flavors and aromas of the grape. The juice should be allowed to settle prior to the fermentation. Fermentation at a low temperature is preferable. In the production of red table wines, on the contrary, the fermentation must be on the skins, which are kept punched down or immersed in the liquid to facilitate the extraction of color and aroma. The pigment, an anthocyanin, is in the cells of the skin in all red and most black varieties, and is not released until the semipermeability of the cell walls is destroyed by the alcohol produced in the fermentation. When the color of the fermenting wine is sufficiently dark, the juice is drawn off, and the fermentation completed off the skins. This procedure also fosters the extraction of other substances, particularly tannin. In the production of rosé wines the period of fermentation on the skins is very much reduced, and usually only grapes of moderate color are used. The fermentation of juice alone is carried out in closed containers to utilize the protection of the atmosphere of carbon dioxide over the fermenting mass, provision being made for the escape of carbon dioxide.

With the much restricted period of fermentation of sweet dessert wines, it is common practice to ferment on the skins, except where a very light color is desired. In the latter and in the case of dry sherries the crushed grapes are usually allowed to stand until the pomace rises to the surface; then the free-run juice is withdrawn and fermented separately. To facilitate the extraction of flavors and color from the skins in the production of red dessert wines where the fermentation is interrupted soon after it gets well under way, necessitates the utilization of procedures to retard the rate of fermentation. A reduction in temperature is the most desirable means.

Sparkling wines, such as champagne, are made naturally effervescent by a second fermentation in the bottle (or in a closed container). The amount of sugar required to produce the desired pressure and a culture of champagne yeast are added to a suitable table wine that has been brought through the normal fermentation and clarification. It is then bottled in special champagne (strong) bottles which are corked with special corks that are held in place with steel clamps. Since the carbon dioxide

cannot escape, pressure is generated during the fermentation of the added sugar. The pressure (usually about six atmospheres) is governed by the amount of sugar present. The sediment produced in the bottles during the fermentation must be removed. This is accomplished by working it onto the cork, the bottle being inverted (Fig. 10), and then removing the cork and spilling enough wine to sweep out the sediment. The bottles are then refilled with the same wine from another bottle or after adding a small quantity of a special sweetened dosage, and finally they are recorked and the cork tied in place with wire. The sugar in this final dosage does not ferment because of the carbon dioxide content, the pressure and the low level of the yeast nutrients.

FIG. 10. Champagne bottles on rack. Bottles are shaken slightly and turned a bit each day for weeks to work the sediment onto the cork. (*Courtesy of the Wine Institute.*)

Chemical Constituents. Certain chemical constituents of wines are aids

in distinguishing between classes, while others are of use in determining soundness and identity. The alcohol content of table wines must be below 14 per cent, while that of dessert wines is over 18.5 per cent.

The sugar residue is an indication of the completeness of fermentation as well as an indication of the type. Wines with less than 0.2 per cent sugar are "dry", since this amount of sugar is not perceptible to taste. With larger amounts of sugar in the wine, provisions must be made to prevent refermentation or bacterial spoilage. Sweet table wines, according to type, may contain from 0.25 to 6 per cent of sugar. These wines are stabilized by pasteurization, the use of sulfur dioxide, or other means. Dessert wines contain from less than one to 18 per cent of sugar. In these the fermentation is arrested at the desired sugar content by the addition of neutral grape spirits.

Table wines of high total acidity (0.65 per cent or more) taste fresh, fruity and tart, whereas those of low total acidity (below 0.50) are likely to be flat and insipid. Dessert wines, because of their high sugar content, are more acceptable at a lower total acidity. The better ones should have an acidity of 0.40 to 0.50 per cent. A small amount of volatile acid is a normal constituent of wine; it may add to the flavor. However, when the volatile acidity increases unduly (over 0.12 per cent), it becomes objectionable and indicates that the wine is deteriorating.

White table wines are straw to pale yellow, while the white sweet table wines are pale golden in color. An amber tint indicates undesirable oxidation or overaging. The white dessert wines are light amber. Rosé wines are pink in color. Red table and dessert wines should be of a full-red color without blue. Brown is objectionable in all pink and red wines, except in tawny port.

Aromas and Flavors. The constituents that characterize natural wine types cannot be determined readily by chemical means. The flavoring matters and the aroma- and bouquet-contributing substances are present in such small amounts that they have so far been detected only organoleptically, and little has been done to measure them quantitatively. The most obvious and pronounced flavoring substances are those that give the wine its varietal character, such as Zinfandel, Cabernet, Riesling or Muscat. The flavoring substances of these varieties are readily detected in the ripe fruit; those of others, however, are only faintly, if at all, recognizable in the fresh grapes but develop a pronounced character in the wine during aging.

The aroma and flavoring substances of natural wines are principally a combination of aldehydes, alcohols and organic acids. The acids found in wines are acetic, formic, propionic, n-butyric, capric, lauric, caprylic and n-capric. This number of organic acids, as compared to the aldehydes and alcohols, together with their readiness to combine with the same substance or substances to give rise to compounds differing greatly in odor and taste, indicates a prominent role for the acids in, and aids in accounting for the wide variety of flavors and aromas of, wines.

The sherries of commerce are subjected to aging or other treatments which change or add to their natural flavors and aromas. Although the grape variety supplies the suitable base for sherry, much of the distinctive character of the flavor of the Spanish sherries comes from aging under a film of yeast. The film oxidizes alcohol to acetaldehyde and produces other flavoring constituents which enter into the production of the typical sherry flavor. California sherries, on the contrary, derive their characteristic rancid flavor from slow caramelization and oxidation

during storage at 120° to 140° F for two to four months. A moderate temperature slows the rate of oxidation and reduces caramelization, with the development of a more delicate flavor. Other wines of this group derive their flavor from long aging in oak casks.

Vermouth is a wine that has been blended with an infusion of bitter and aromatic herbs. The quality of this wine is governed by the quantities and kinds of herbs used, the method of preparing the extract and the character of the base wine. The most commonly used herbs are fruits of coriander (*Coriandrum sativum* L.), bitter orange peel (*Citrus Aurantium* L.), leaves of Roman wormwood (*Artemisia Absinthium* L.), bark of cinchona (*Cinchona* sp.), European centaury (*Centaurea* ?), calamus root (*Acorus Calamus* L.), roots of elecampane (*Inula Helenium* L.), elder flowers (*Sambucus* sp.), fruits and roots of angelica (*Angelica Archangelica* L.), rhizomes of orris (*Iris florentina* L.), roots of gentian (*Gentiana lutea* L.), bark of cinnamon (*Cinnamomum* sp.), cloves (unopened flower buds of *Eugenia caryophyllata*) and the seeds of nutmeg (*Myristica fragrans* L.) and of cardamon (*Elettaria Cardamomum* (L.) Maton). Commonly the herbs are mixed as desired by the producer and then placed in the wine base until it has absorbed the desired flavors and aroma, or the mixture is extracted with alcohol and added in the proper quantity to the wine base.

Aging. Once the fermentation is completed in the case of table wines or arrested in dessert wines, the yeasts and suspended fibrous materials settle rapidly. If held under favorable conditions, the wine next undergoes a series of changes which constitute the development incident to aging.

Timely removal of the wine from the lees—racking—not only aids in its clarification but also prevents the extraction and absorption of undesirable flavors, odors and nutrients from the deposit of yeasts. As the wine will continue to throw additional sediment, the racking must be repeated two or three times the first year and usually two times during the following year or years. In the racking other changes, such as the loss of carbon dioxide and the absorption of oxygen, occur, and these changes again inaugurate other reactions.

Storage in wooden casks of moderate size facilitates the oxidation under conditions that foster normal development of the wine. There is a decrease in the fixed acidity resulting from deposition of acid tartrates and sometimes due to a fermentation of malic to lactic acid; a decrease in the tannins and coloring matter; and an increase in the aldehydes, acetals and similar substances. Once the wine has attained its desired development in the wood, it is bottled. Binning of the bottled (Fig. 13) wine for a time is essential to further esterification and the attainment of a delicate and characteristic bouquet. The proper balance of cask and bottle aging must be determined for each wine. For example, French Burgundy is aged in the wood for a number of years and in the bottle only one to two years, while the reverse is true of French claret.

The period required for aging depends on the type of wine, the nature and extent of the aeration, the size and kind of storage container, and the storage temperature. A wine of high extract and tannin content will age slowly in comparison with a light wine of low tannin content. With small casks and frequent racking, there is an increase in the absorption of oxygen, and aging is more rapid. Over-aeration will result in the absorption of so much oxygen that the wine will taste flat, and if such a condition prevails for a long period the wine will take on an oxidized taste or may spoil. Table wines develop most favorably when stored at temperatures

between 50° and 60° F. For dessert wines the temperature may be somewhat higher.

Although table wines of low quality profit but little by aging, since freshness and fruitiness are their greatest assets, aging is of utmost importance for high-quality wines of all types. It is the only means whereby the potentialities of such wines can be brought to their full fruition. Dessert wines of all degrees of quality must be aged in order to ameliorate the grape spirits with the wine and produce a reasonably smooth product.

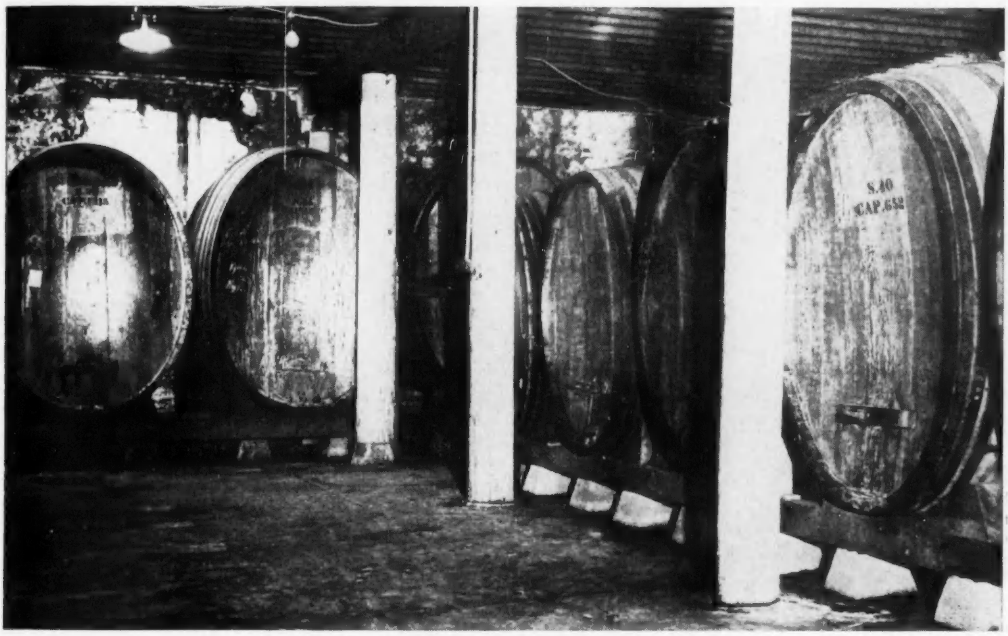


FIG. 11. Moderate-sized oak casks for the aging of quality wines. (*Courtesy of the Wine Institute.*)

Clarification. Well-balanced, sound wines usually clear themselves perfectly during normal aging. This may not be true of less well-balanced products. The latter require aids to assist the clarification, such as fining and filtration.

In fining, an agent such as gelatin, isinglass, casein or bentonite is added to the wine. By either combining chemically with the colloids or by physical action these agents cause the suspended particles to coagulate and settle. The proper fining agent must be selected so that the quality of the wine will not be impaired by its action. All such agents take something out of the wine, but their action is different, hence the need for fitting the agent to the particular wine to be fined.

Filtration is a supplement to racking or fining. It is used when the suspended materials fail to settle, or it may be used in conjunction with fining to facilitate the development of ordinary bulk wines for early market. Most wines are given a polishing filtration to remove all suspended substances during the process of bottling.

Wine By-Products. Grape spirits, pomace and cream of tartar are the principal by-products in wine production. Of these, grape spirits, obtained from the pomace or lees, is the most widely recovered by-product. Its recovery may be effected by direct distil-

lation of these materials or by washing, displacement or pressing and subsequent distillation.

FIG. 12. Huge redwood tanks for the aging of standard wines. (*Courtesy of the Wine Institute.*)

The pomace constitutes $\frac{1}{10}$ to $\frac{1}{5}$ of the weight of the grapes. It may contain some sugar, a small amount of alcohol, or neither, according to the type of wine that is being produced and the general operation of the fermentation room. The bulk of the pomace is skin

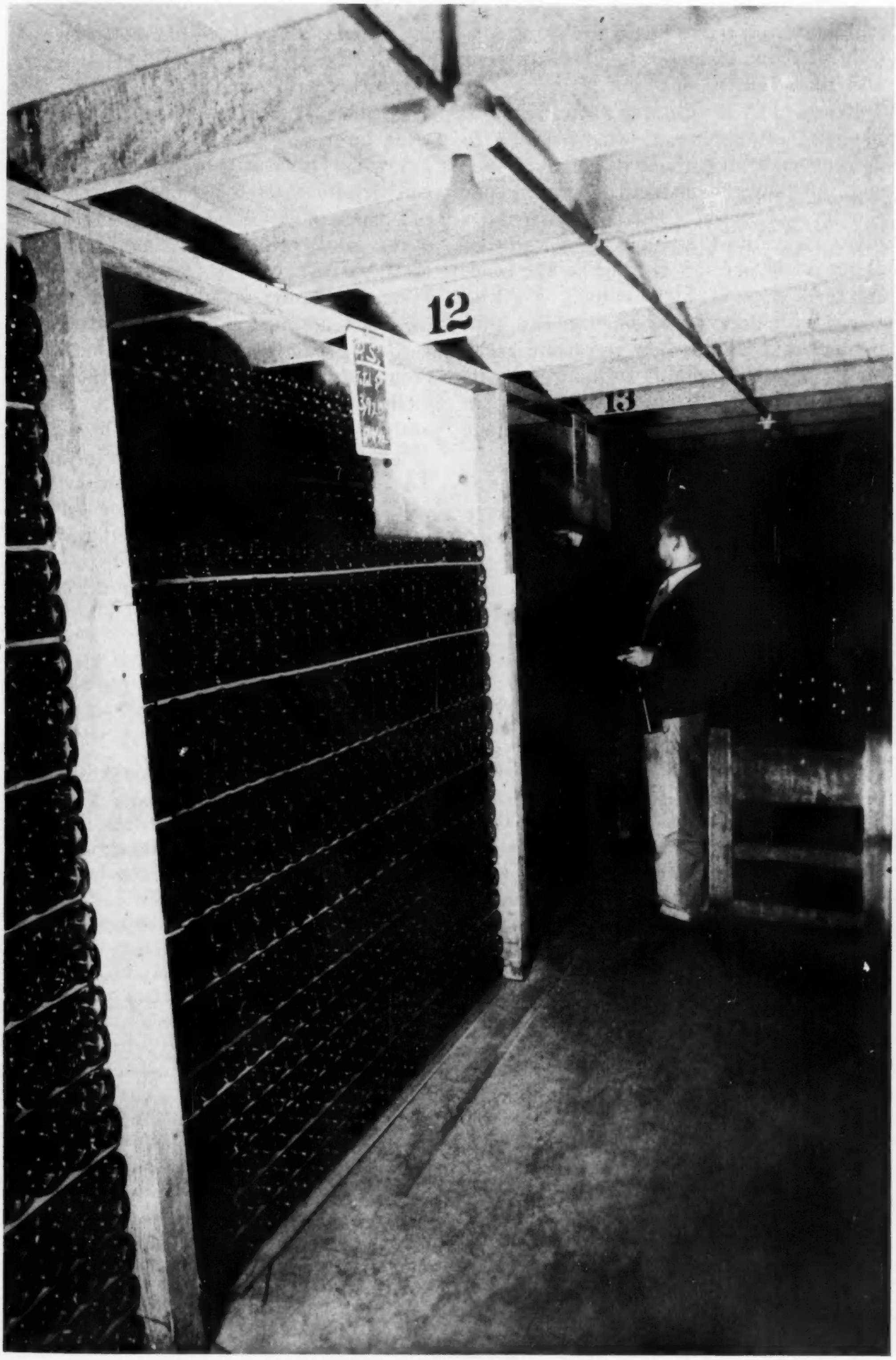


FIG. 13. Placing bottled wine in bins. High quality wines must be given some time for aging in the bottle if they are to attain their highest development. (*Courtesy of the Wine Institute.*)

and seeds; on a dry basis, the skins contribute about 25 per cent of the weight and the seeds 60 per cent.

Fresh pomace contains from 35 to 70 per cent of water and when dry $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent of nitrogen, about $\frac{1}{2}$ per cent of phosphorus, and $1\frac{1}{2}$ to $2\frac{1}{2}$ per cent of potassium. On the basis of its nitrogen content, pomace has a value of about $3.00 per ton applied to the land. As feed it is of little value. Feeding trials with dairy cows have shown that pomace is decidedly low in total digestible nutrients (probably influenced by its lignin content), high in fiber, low in protein and inferior to good roughage in feeding value.

The oil of the seeds in the pomace is extracted in some countries. The content of oil varies between varieties from about 5 up to 12 or 15 per cent of the dry weight of the seeds. The tannin content of the seeds has a similar status. It has value, but there has not been sufficient demand to justify the cost of extraction and purification in America.

Cream of tartar became an important wine by-product during World War II. Previously the only tartrates of American origin were those obtained by the natural separation occurring during the aging and cellar treatment of wine. Many of the wineries of Europe, however, regularly saved all pomace and lees, and scraped their storage tanks to recover cream of tartar. To obtain the cream of tartar from pomace, the latter is thoroughly extracted with hot water, and the extract is treated with calcium chloride to bring about precipitation. The recovery of tartrate from stillage can be fitted into a system for the disposal of this highly putrescible material; the fining, settling and the precipitation of the tartrates should be the first steps in the disposal system.

Utilization Abstract

Flax. The term "linen" includes all yarns spun and fabrics woven from flax fiber; flax is the raw material, linen the manufactured product. Egyptian "mummies 5,000 years old have been found wrapped in linen so fine that it could not be duplicated today . . . The Swiss Lake Dwellers used linen, and in later times the Roman armies used linen rope for bridges as well as for fabrics" . . .

While nearly all European countries do or did produce flax to some extent, Russia is the world's greatest producer of it, with four to six million acres devoted to the crop. Argentine has had up to four million acres; Canada up to two million; and Ireland, Belgium, Japan, Holland and France, 200,000 acres each. Most of this acreage outside Europe is devoted to growing seed flax, the shorter-stalked, more branching variety. This applies also to the United States where in 1947, 4,026,000 acres were harvested, of which, 1,373,000 were in Minnesota. Minnesota and the Dakotas accounted for 85% of all the flax raised in the U. S., and other States with more than 100,000 acres were Kansas, California and Montana. The largest acreage of flax ever gathered in the U. S. was in 1943 when 5,847,000 acres were harvested, yielding about 52 million bushels of seed worth about $150 million. The 1947 U. S. crop was approximately 40 million bushels, worth about $300 million. One third of that was a cash crop in Minnesota.

Except for the relatively small portions of these annual harvests of seeds used the succeeding years for reseeding, the harvests have been utilized in producing linseed oil, so vital in the linoleum, paint and allied industries; and the enormous quantities of flax stalks left over have until recent years been a waste product to be burned or otherwise disposed of. This wasteful situation has been corrected by the manufacture of rugs, cigarette paper, currency, airmail paper and envelopes, and Bible paper from the stalks. (*P. R. Moore, Chemurgic Digest* 7(4): 15. 1948).

Essential Oils—*A Brief Survey of their Chemistry and Production in the United States*

Essential oils can be produced in this country, but extensive investigations and careful planning are of prime importance.

A. J. HAAGEN-SMIT
California Institute of Technology

Introduction

The essential oil industry occupies a very prominent position in our life. Almost continually we are reminded in some way of its products, such as perfumes and flavoring agents. The importance of these substances can hardly be overestimated, and in the past, wars have been fought to obtain sources of and markets for the essential oils. While at the present time other oils have the doubtful honor of being fought about, the past few years have made us feel again how dependent our civilization is on the use of cosmetics and flavoring agents. Due largely to historical reasons, the regions around the Mediterranean have long been the center of the industry, and only gradually have other countries decided to produce some of the oils themselves. Most of these foreign industries are working with low paid labor. Often farmers with their entire families, young and old, collect plant material for wages amounting to a few cents per day. Countries such as the United States with much higher minimum wages are therefore at a great disadvantage in the building up of similar industries of their own. If calling for tariffs, to balance somewhat the advantage of foreign cheap labor, is deemed undesirable, it is necessary to utilize all the scientific and engineering knowledge available to overcome this handicap. In the following we shall point out some cases where against heavy odds, through basic studies of all phases of the problem, successful industries were founded. Before doing this, however, it is necessary to outline briefly our present day knowledge in this field.

Occurrence and Extraction of Essential Oils

Occurrence. Microscopic examination of plants with characteristic odors shows that distinct cells or spaces in the plants are filled with oily droplets which stain with fat dyes. There are, however, two great differences which distinguish these oils from fatty oils: their characteristic odor and their volatility. Evidently the oil is the carrier of the "essence" of the plant, and the oils have therefore been referred to as "essential oils".

In many cases the cells which contain the oils are epidermal cells or modifications of these, such as excretion hairs, with the secretion product usually accumulated between the cuticle and the rest of the cell wall. A slight touch is sufficient to break this thin outer membrane and to release the oil with its typical smell. In other cases the oil is lodged in internal glands which are distributed throughout the plant and which have been formed by deposition of the

oils between the walls of the cells and by dissolution of the surrounding cells (4).

If the essential oils are contained in easily ruptured cells of the epidermis, simple pressing, as is practiced on a large scale in the lemon and orange oil industry, will release the oil. Plants containing the oil in cells distributed throughout the plant, the walls of which are often reinforced with cork, need grinding and cutting before the oil can be released.

In some cases the volatile products are not present originally in the plant material but are formed by hydrolysis from glucosides. Upon grinding the cells, enzymes are set free to split off the volatile products, such as methyl salicylate and benzaldehyde, which are, respectively, the main constituents of wintergreen oil and peach kernel oil.

Steam Distillation. The method most frequently used to separate the volatile oil from the plant is steam distillation. The distillation is carried out in a still consisting of a metal or wooden retort or vat, a condenser and a receiver. In its simplest form the method consists of packing the ground or cut material together with some added water into a still, heating the outside of the still and condensing the vapors evolved. These primitive methods are still used in many countries, but in the more modern methods the water necessary for carrying over the oil is produced in separate generators, and the steam is blown through the plant material which has been packed in the still. The steam heats the plant material and volatilizes the oil, and steam and oil vapors together are condensed and collected in a small receiving flask where the oil separates and forms in most cases a layer on top of the water. The water is released from an opening at the bottom of the receiver through a bent tube, the outlet of which is on a level with the top of the oil layer. In this way the distilled water flows from the receiving vessel as it enters the condenser, while the oil layer remains in the flask and steadily increases in volume until the plant material has become exhausted, usually within two hours. This method is applied in the United States to the production of oils of turpentine (from resin of *Pinus palustris* mostly), peppermint (from leaves of *Mentha piperita*), eucalyptus (from leaves of *Eucalyptus* sp.), cedar (from heartwood of *Juniperus virginiana*), erigeron (from entire plant of *Erigeron canadensis*), witch-hazel (from the young branches of *Hamamelis virginiana*), wormwood (from entire plants of *Artemisia Absinthium*) and lemon grass (from leaves of *Cymbopogon citratus*).

The advantage of the steam distillation method lies in its lower temperature at which the oil components distil as compared to distillation without water. For example, in the distillation of oil of turpentine the main constituent, α-pinene, boils at 155°–156° C. at atmospheric pressure but distills over at 96° C. upon steam distillation.

Sievers (13) described in detail a still which can be used for the commerical distillation and pilot experimentation of a few acres of essential oil plants. For those who have only a small plot of essential oil plants and who want to have the pleasure of distilling their own oil, a still can be constructed at small expense from a ten-gallon milk can, a metal tube for condenser, a smaller can for developing steam and a decanting bottle connected as in Fig. 1.

Enfleurage and Solvents. When flowers are subjected to steam distillation considerable destruction of their odoriferous principles takes place. In such case extraction with fat, or preferably with low boiling solvents like petroleum ether and benzene, is used.

In a number of cases neither steam distillation nor extraction will give a satisfactory yield of oil because the volatile material is produced while the plant

is living and only small amounts are stored in the plant tissue. This is, for example, the case with the odors of tuberose (*Polianthes tuberosa*) and jasmin (*Jasminum* spp.). We must give the flower the opportunity to continue to live and excrete its odoriferous components in order that we may collect them. The perfume industry in southern France solved this problem by using the property of fats to absorb the fragrant substances. This so-called "enfleurage process" is carried out in the following manner.

Glass plates, two or three feet square in wooden frames, are covered on both sides with purified tallow or lard; on this the flowers are spread. Large stacks of these plates are piled one upon the other about two inches apart. The flowers are left for one or two days completely surrounded by the fat, and are then replaced by new ones. The fragrant substances from several dozen successive layers of flowers are absorbed by the fat, and the fragrant principle is then extracted from the fat by means of alcohol in which the fat is insoluble. Subsequent concentration of the alcoholic extract gives one of the most expensive products of perfume manufacture.

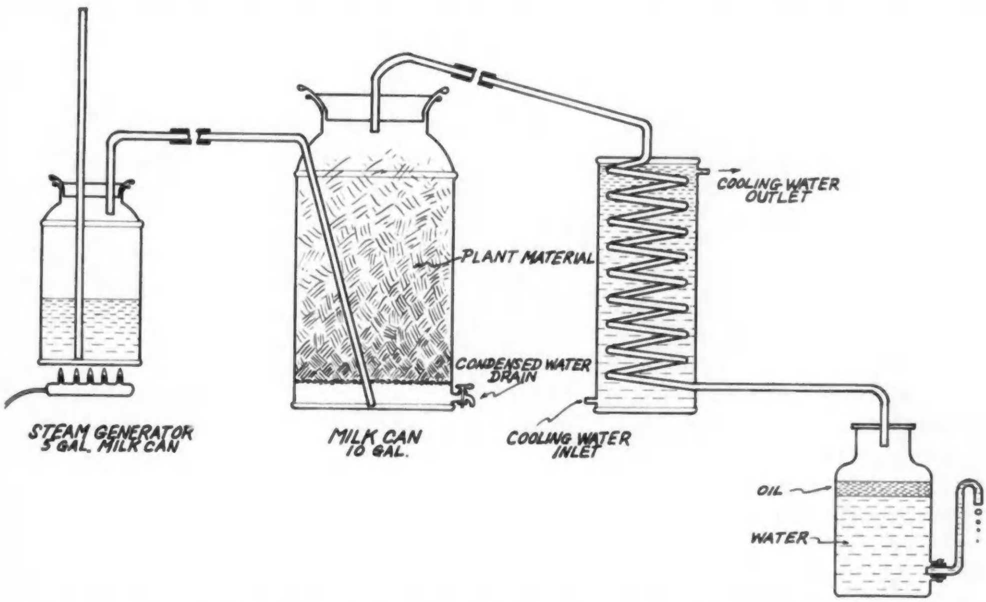


FIG. 1. Diagram of a simple distillation apparatus for home extraction of essential oils from plant material.

Chemical Composition of Essential Oils

By definition the essential oils are volatile products obtained from plants. It is clear from such a definition that this group will harbor a large number of substances of totally different chemical structure. However, the requirement that the compound be volatile limits the possibilities considerably. Because of this limitation we must look for members of this group among compounds of a boiling point not much higher than 300° C., which means that the number of carbon atoms in these compounds rarely exceeds twenty. This excludes fats, sterols and other higher molecular fat-soluble materials. The compounds can not be too highly hydroxylated, thereby

excluding sugars, glycosides and carbohydrates. Strongly ionized compounds, namely, salts, strong acids and strong bases, are not found among the components of the oils. However, within these limits set by the definition the variety of compounds is still very large, including substances which belong to a great number of classes of organic compounds: aliphatic and olefinic hydrocarbons with their derivatives containing oxygen, nitrogen and sometimes sulfur; aldehydes; ketones; alcohols; acids; esters; lactones; amines; mercaptans. Many of them have ring systems containing usually five or six carbon atoms in the ring; other compounds have one of these ring carbon atoms replaced by a nitrogen or by an oxygen atom.

It is not practical to classify this wide variety of substances according to their chemical characteristics. However, one can classify them on a biochemical basis by grouping them as compounds which are related through their biosynthesis. In this way compounds composed of a straight chain of carbon atoms, regardless of their oxidation state and therefore including alcohols, aldehydes, ketones, esters and acids, are discussed together.

We find hydrocarbons as low as heptane in *Pinus Jeffreyi*, for instance, the oil consisting nearly wholly of this compound and thereby closely resembling normal gasoline. Other turpentines contain nonane and undecane, and there are oils wherein small amounts of higher hydrocarbons have crystallized out. These precipitates are known as "stearoptenes", and some of these contain molecules with as many as 29 carbon atoms and 60 hydrogen atoms. Alcohols, aldehydes, acids and their derivatives of the straight chain type are widely distributed, especially in fruit flavors. Interesting members of this group are leaf alcohol and its aldehyde (Fig. 2, I & II). Homologues of these alcohols and aldehydes are the major constituents of cucumber oil which consists largely of nonadiene-2,6-ol-1 (Fig. 2, III) with some of the corresponding aldehyde.

Another large group, containing carbon atoms with a benzene ring, are important in the perfume and flavor industries. Representatives of this group are to be found in the oxygen derivatives of benzene, such as benzaldehyde (Fig. 2, IV), the main component of bitter almond oil (*Prunus Amygdalus* var. *amara*) and vanillin (Fig. 2) the aromatic principle of vanilla beans (*Vanilla* spp.). A large subgroup contains a benzene ring substituted with a straight chain of three carbon atoms, mostly a propenyl chain. Representatives are found in oil of cloves (*Eugenia caryophyllata*) and sassafras oil (*Sassafras albidum*) which contain, respectively, eugenol (Fig. 2, VI) and safrole (Fig. 2, VII).

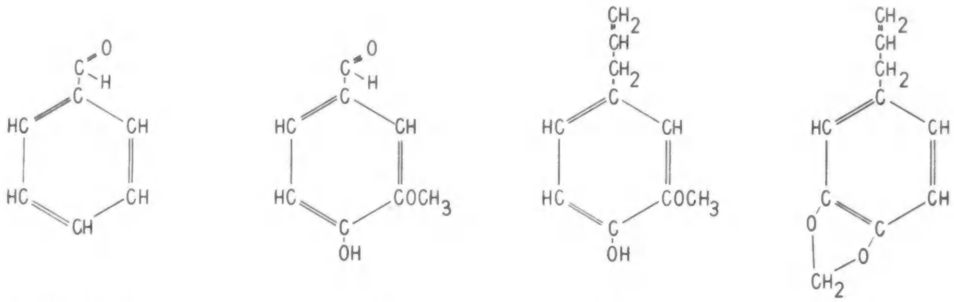
In the third group we can place about 500 compounds which have as elementary building units a branched C_5 chain. To this group belong the terpenes which are so characteristic for a number of essential oils, such as turpentine and peppermint. In the last category we must group all those compounds which do not find a place in the other three groups. These are the mercaptans and thio ethers, which are heterocyclic compounds containing nitrogen as well as oxygen in the ring. Examples are found in the occurrence of indole (Fig. 2, VIII) in several flower oils. Asafetida, the gum resin of *Ferula assafoetida* which has been the notorious ingredient of many historical recipes, contains an allyl secondary butyl disulfide (Fig. 2, IX).

The terpene group is certainly the most typical of the essential oil components, and for a through understanding of the essential oil problems it is necessary to describe more fully their chemical structure. The molecules of a large

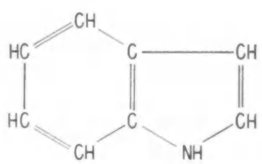
$CH_3-CH_2-CH=CH-CH_2-CH_2OH$ LEAF ALCOHOL (I)

$CH_3-CH_2-CH=CH-CH_2-\underset{H}{C}=O$ LEAF ALDEHYDE (II)

$CH_3-CH_2-CH=CH-CH_2-CH_2-CH=CH-CH_2OH$ NONADIENE-2 6-OL-1 (III)



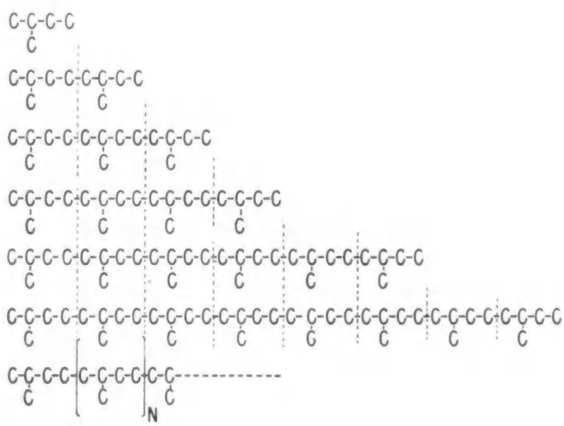
BENZALDEHYDE (IV) VANILLIN (V) EUGENOL (VI) SAFROLE (VII)



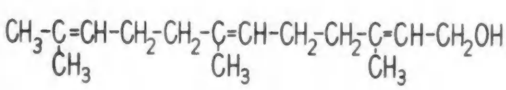
INDOLE (VIII)

$CH_3CH_2CH(CH_3)S\cdot SCH{:}CHCH_3$

ALLYL SEC BUTYL DISULFIDE (IX)



HEMITERPENES	5
MONOTERPENES	10
SESQUITERPENES	15
DITERPENES	20
TRITERPENES	30
TETRATERPENES	40
POLYTERPENES	N = 500-2000



FARNESOL (XXII)

Fig. 2. Formulae of some organic compounds associated with essential oils.

number of terpenes are composed of a multiple of 5-carbon atoms, and have the formula $(C_5H_8)_n$ in which n might be

carbon skeletons of the different groups, from hemiterpenes to polyterpenes, with their names are listed in Fig. 2. The

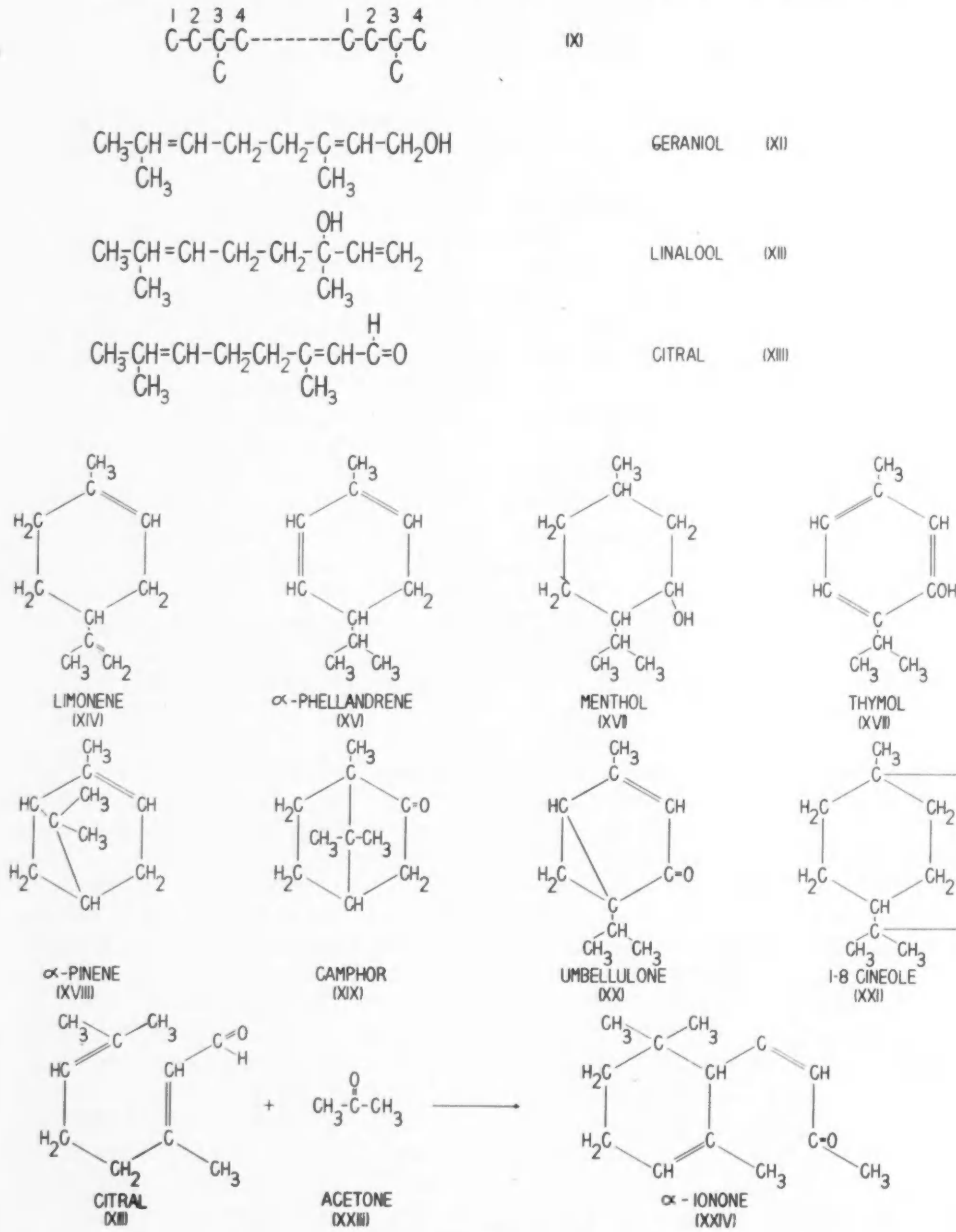


FIG. 3. Formulae of some organic compounds associated with essential oils.

1, 2, 3, 4, 6, 8 and even 500–2,000, as in the polyterpenes such as rubber. The carbon atoms are arranged in the pattern of an unsaturated branched chain

composed of identical units of five carbon atoms. The most important group in the volatile oils is the C_{10} group, in which we usually have a so-called head-to-tail union of these C_5 units. That is, carbon 4 is united with the carbon 1 from another C_5 chain, forming a chain of eight carbon atoms with two methyl groups branching from the main chain (Fig. 3, X).

Hydrocarbons of this type occur in few oils; more frequent are the oxygen derivatives. Some of the most valuable perfume ingredients belong to this group. The structure of geraniol, a component of rose oil; linalool, present as acetate in lavender oil; and citral, the main constituent of lemon grass oil, are also presented (Fig. 3, XI–XIII). Apart from the oxygen present in all three compounds, the presence of the double bonds should be noted. These double bonds are an indication of the unsaturated and therefore reactive character of these substances. Due to this reactivity the carbon atoms in a molecule might give rise to additional linkages with the formation of mono- and bi- cyclic ring systems. Many of these ring compounds occur in nature, although at present it is not known whether this ring closure takes place during the synthesis or secondarily after the open chain has been formed. Limonene (Fig. 3, XIV), containing one carbon ring, is a most common component of essential oils, and is a major constituent of orange and lemon oils. An alcohol of the same grouping is menthol (Fig. 3, XVI), present in peppermint oil. A phenol, thymol (Fig. 3, XVII), with strong disinfecting action is present in thyme oil. If two more carbon atoms are interlinked in the molecule we obtain compounds with two rings. One of these bicyclic types, α-pinene (Fig. 3, XVIII), is found as the major component of commercial turpentine and is one of the most widely distributed terpenes. Other representatives containing two rings are camphor (Fig. 3, XIX), present in the oil of *Cinnamomum camphora* and many other oils, and umbellulone (Fig. 3, XX), the active principle of California bay oil (*Umbellularia californica*) which causes a severe headache within a few seconds of inhalation, due to a sudden rise in blood pressure.

The next class of terpene compounds contains three C_5 units and are called "sesquiterpenes", since they contain one and one half times as many carbon atoms as the monoterpenes. The sesquiterpene group is less volatile than are the monoterpenes and is to be found among the higher-boiling fractions of the essential oils. One of the most valuable of the sesquiterpenes is an alcohol, farnesol (Fig. 2, XXII), which is built like geraniol but contains one more five-carbon group. It has, like geraniol, a flowery smell, which is, however, not so intense, and more closely resembles lily-of-the-valley. The addition of five carbon atoms increases the possible number of isomers which makes the study of these compounds considerably more difficult. Nevertheless the chemical workers could establish regularities in molecular structure similar to those found in the terpene series. Here, too, an interlinking of the carbon atoms is frequently seen, and as a consequence, the occurrence of cyclic derivatives. In this group belong the compounds which give to some oils, such as chamomile (*Matricaria Chamomilla*), spike (*Lavandula latifolia*) and camphor (*Cinnamomum Camphora*), their blue or green color. These colors are not, as was formerly supposed, due to the copper content originating in the stills, but to intensely blue hydrocarbons called "azulenes" with the formula $C_{15}H_{18}$. It is interesting to note that similar compounds are formed upon cutting some mushrooms. In general, this group of sesquiterpenes

does not have the strong and characteristic odor of the more volatile monoterpene group. However, the C_{15} compounds play an important role in preventing the more characteristic smelling, lower boiling components from evaporating too fast, and they therefore act as natural fixatives. On the other hand, cases are known, as for example in cedarwood oil, where the sesquiterpene itself is responsible for the typical and highly valued odor.

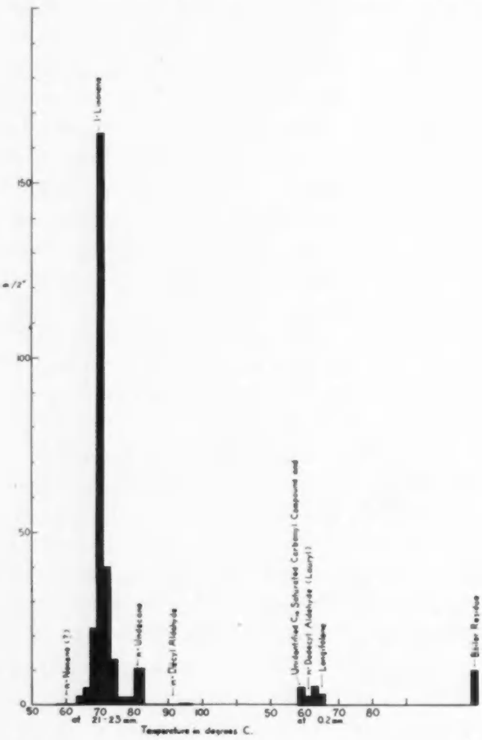


FIG. 4. Straight chain hydrocarbon and terpene composition of turpentine from *Pinus Torreyana*.

The next group of compounds containing four C_5 units we find in small quantities in the highest boiling fractions of the essential oils. Because of the high boiling point of the oxygen derivatives, these are not found in the volatile parts of the oils but are present as rosins and kopals in the residues of the turpentine distillation.

Even less volatile are higher members of the terpenes. These are therefore not of immediate importance to the essential oil industry but are mentioned to round off the total picture of this group of biochemically related compounds.

Molecules containing 30 carbon atoms built along the same principles as the terpenes are found among the saponins. Many drugs, such as sarsaparilla from the dried roots of *Smilax aristolochiaefolia* and *S. Regelii*, owe their pharmacological and detergent action to the presence of these compounds. Still higher isoprene homologues are found in the group of carotinoids (C_{40}), the red and yellow plant pigments. The terpene series is closed with the polyterpenes which contain up to thousands of C_5 units. In this group belong the naturally occuring rubbers.

In the chemical study of the oils, steam distillation is usually followed by a fractionation process which separates the oil components according to their boiling points. To obtain quickly an idea of the composition of an oil, we can represent the fractionation data in a graph, such as Fig. 4, where the ordinate represents the percentage of oil distilling over at an interval of one degree. As illustration of such a fractionation, the results of a systematic study on the composition of the turpentines of the genus *Pinus*, undertaken by N. Mirov and the author, were selected. It has been shown that most turpentines are rich in α-pinene (Fig. 3, XVIII). There are, however, oils which differ radically from the usual pattern. In some cases, as was mentioned earlier, we find that the oil consists of nearly pure normal heptane. The Torrey pine turpentine, as seen from Fig. 4, consists of a mixture of the two major groups—straight chain hydrocarbons and terpenes. In the first place we notice the monoterpene. limonene (Fig. 3, XIV), and the sesquiterpene, longifolene, and superim-

posed on these are the straight chain hydrocarbons, nonane, undecane and their oxygen derivatives, decyl and lauryl aldehydes.

An example illustrating a different combination of major groups, the simultaneous occurrence of the terpenes and the benzene derivatives, is seen in the analysis of California bay oil (*Umbellularia californica*). The main constituents are the terpenes umbellulone (Fig. 3, XX) and cineole (Fig. 3, XXI). The benzene group is represented by safrole (Fig. 2, VII) and by a methyl derivative of eugenol (Fig. 2, VI).

Conversions of Oil Components

Knowledge of the chemical composition of essential oils is of importance for judging the possibilities in new oil projects as well as in established ones. The chemist is able to convert many oil components into other compounds which may have greater commercial application. Interesting examples are found in the conversion of the terpene alcohol geraniol (Fig. 3, XI) into linalool (Fig. 3, XII), and *vice versa*. Both compounds are valuable perfume constituents, and, depending on market conditions, the reaction can be conducted in such a way that geraniol is converted into linalool which finds use as acetate in lavender composition, or linalool may be converted into geraniol and its esters which are used to impart a rose note to many floral compositions.

Oils containing citral (Fig. 3, XIII) derive a great deal of their importance from the versatility of this aldehyde. It is possible to prepare from this lemon smelling substance rose-like geraniol (Fig. 3, XI), while by addition of acetone (Fig. 3, XXIII), ionone (Fig. 3, XXIV), which smells like violets, can be formed. Other examples are the large scale conversion of α-pinene (Fig. 3, XVIII) from pine oils into camphor (Fig. 3, XIX), and the oxidative degradation of eugenol (Fig. 2, VI) from oil of cloves to vanillin (Fig. 2, V).

One of the most common terpenes, limonene (Fig. 3, XIV), abundantly available in lemon and orange oils, has often been studied from this point of view. Desirable conversion products are thymol (Fig. 3, XVII) and its hydrogenation product, menthol (Fig.3, XVI). Both substances can be made from limonene, but also from other sources, such as umbellulone (Fig. 3, XX) from bay oil and α-pinene (Fig. 3, XVIII) from turpentine, and time will show whether these processes are commercially profitable. More recently special attention has been paid to converting the cheaper oil constituents into polymerization products to serve as plasticizers, plastics, *etc.*

Variations in Composition of the Oils

It is fortunate that the composition of any type of oil varies to a large degree and that the variations can be brought about by different agricultural and climatic conditions and through the use of related species and hybrids. Through the proper choice of these conditions and of plant material it is therefore possible to grow plants which contain the most valuable oil in the highest percentage.

An excellent example of such an investigation to establish the optimum commercial opportunities for a given type of oil has been carried out by Penfold and Morrison (5) in Australia. Due to the abundance of the species of *Eucalyptus*, a great deal of effort has been made in the study of this genus of the family Myrtaceae. This investigation was not limited to the analysis of the most common species. On the contrary, of the 500 species and 150 varied forms, the oils from about 200 species were investigated.

The results of these chemical studies showed that the oils contain a variety of components, 50 of which have been well characterized. On the basis of these findings the *Eucalyptus* oils have been classified into three groups:

I. Oils containing cineole (Fig. 3, XXI), used for inhaling in the treatment of colds.

II. Oils containing a large percentage of phellandrene (Fig. 3, XV) and less than 70% cineole. These oils are used mostly for their solvent properties, as in cleaning solvents and insect sprays.

III. Oils containing a large percentage of terpenes of the acyclic type, such as citral (Fig. 3, XIII), its reduction product citronellal and the acetic acid ester of geraniol (Fig. 3, XI). Their low content of the camphor- and mint-like smelling substances of the *Eucalyptus* in groups I and II makes this oil valuable to the perfume industry.

Studies on the influence of climate and soil upon the formation of essential oils in plants were also made. Also studied was oil formation in the different stages of development of the plant. In general, it has been shown that the highest production of oil occurs during intensive growth. The composition of the oils, too, is subject to different growth conditions, as was shown by the Australian work on the oil of young *Eucalyptus* leaves. Some compounds in these oils, such as the terpene hydrocarbon phellandrene, may appear during spring and summer only to disappear completely towards winter when oxidation products take its place.

In these studies the interesting observation was made that morphologically identical trees contain greatly different oils. A systematic survey of the oils from individual trees showed that four entirely different compositions could be found. How widely different these compositions are can be seen from the following tabulation cited from Guenther's monograph on Australian eucalyptus oil (5):

E. dives Type contains about 50 per cent piperitone, no cineole and almost 40 per cent phellandrene.

E. dives var. "A" contains about 5 per cent piperitone, no cineole and about 75 to 80 per cent phellandrene.

E. dives var. "B" contains 10 to 20 per cent piperitone, 25 to 45 per cent cineole and a quantity of phellandrene.

E. dives var. "C" contains less than 5 per cent piperitone, 60 to 75 per cent cineole and no phellandrene.

Especially interesting is the difference between the oils of varieties "A" and "C". One is a good industrial solvent, while the other, on account of its high cineole content and the absence of phellandrene, qualifies as a medicinal oil. This knowledge is of great importance for the collecting of the oil, since proper selection of the trees makes for greater homogeneity in the product. Similar findings were made in the species *Eucalyptus radiata* and *E. Australiana.*

That such a biochemical difference between trees which are indistinguishable by morphological characteristics is more common, can be seen from our studies of the compositions of the oleoresins collected from *Pinus washoensis.* The trees were growing close together on Mount Rose overlooking Lake Tahoe, and the morphological study of the trees left no doubt as to their identity. However, some of the oils were laevo-, others, dextro- rotatory. Chemical analysis showed that some of the oils contained a large percentage of Δ^3 carene, while this terpene was nearly absent from others and replaced by β-pinene.

Lemon-Grass Oil in the United States

In the United States the development of the lemon-grass industry shows a similar understanding of the basic problems involved, and a great deal of thorough research was carried out before large scale planting of the essential oil-bearing plants was started (2, 3, 10). It is interesting to review briefly its development because it shows clearly the difficulties that the essential oil industries face in this country.

To find year-round employment for agricultural workers, the United States Sugar Corporation and the U. S. Dept. of Agriculture in Florida were looking for a suitable enterprise. In 1934 cultivation and distillation of lemon grass (*Cymbopogon citratus*) was selected as a promising possibility. To show one of the main difficulties of this project I quote Dr. Bourne: "A rather comprehensive study of labor costs in foreign countries supplying the American market with duty-free oil was next made. With agricultural workers in the lemon grass industry receiving between 8 cents and 25 cents daily in these foreign countries and then shipping the oil duty-free to America to compete with agricultural laborers in the area receiving a minimum of $1.60 daily wage plus housing, medical assistance and several other perquisites, many innovations for saving excessive and expensive labor costs were naturally sought to overcome this unfair competition".

On experimental plots the amounts of potassium, phosphorus and nitrogen were determined with which the local soil would give a maximum yield in oil. In this way with the best fertilizer combinations, in the period of June 8 to October 1 (1936), yields of 43 tons of green lemon grass per acre were obtained. The amount of lemon-grass oil per acre amounted to about 150 pounds. Studies were then made on planting, cultivation, harvesting, loading and transportation procedures. Harvesting machines were built which could harvest and load in baskets placed in each field wagon. At the processing plant these baskets are lifted and placed in the stills where steam removes the oil. In all of the operations the grass is never touched by hand.

In 1939 the price of foreign oil f.o.b. New York was as low as 35 cents per pound. Even with the improvement in agricultural and processing methods commercial production at a profit was out of the question. Efforts were made to develop by-products. It was found that dehydrated lemon-grass pulp containing 35% cane molasses makes an excellent feed for finishing beef cattle in Florida when supplemented with small quantities of a protein concentrate.

In 1941 Dr. Bourne wrote: "In view of the successful by-product utilization, and the establishment of the industry on the basis of both oil and cattle feed, competition with foreign producers can now be fairly met. The industry has therefore been expanded considerably in order to supply American producers in this time of crisis with a secure source of fresh oil having a minimum of 75% citral content and also give the cattle men of Florida a reasonably priced feed product for finishing steers economically".

How timely this lemon-grass project proved to be is shown by the fact that while in 1938 the imports of lemon-grass oil amounted to half a million pounds, during the war this continent alone was the main supplier through its plantations in Guatemala and in Florida. This enterprise was hailed as a real contribution to the independence of the United States in the raw materials of the oil industry and was praised for its founding on real business economics.

In 1945 we find another article by Dr. Bourne. During the intervening period

the lemon grass industry went through a boom period, when in August, 1942, $4.35 per pound of oil was paid. But only six months later this price was reduced to $1.15 per pound. In 1943 the price fell as low as $0.64 per pound. Notwithstanding all the ingenuity with which the lemon-grass industry was created, a loss was sustained during these years, due to the increased costs of labor and material. An industry is described which at its birth had some good fairies, such as the sugar industry and the U. S. Dept. of Agriculture, at its bedside. A great deal of ingenuity is shown overcoming all kinds of technical difficulties. Economically it fills a necessity in supplying year round employment in conjunction with the sugar industry. Nevertheless such an industry is fighting a losing battle. The scientist would do well to recognize that, when he has carried his task to perfection, the economic conditions will ultimately determine the viability of the enterprise.

In a considerably better position are those oil industries which were created as outlets for by-products. In the United States we find an excellent example of this type in the utilization of the by-products of the citrus industry. In a review in this journal by Glen H. Joseph (11) it was pointed out that "Wisdom in planning with confidence, foresight and patience in research and development, converted a botanical wastage to a national industry doing an annual business of more than $125,000,000. Students of economic botany may well pause to review this example of chemurgy as an illustration of the possibilities in their respective phases of this field". The hundreds of references to be found yearly in Chemical Abstracts testify to the tremendous volume of work that has been and is being done in this field. Although the citrus industry is primarily based on the consumption of the fruit as food, the research program has produced so many useful by-products, such as essential oils, pectins, pectates, citric acids, flavanone-glucosides, molasses and stock food meal, that the by-products now form a valuable part of the industry.

Other essential oils produced as by-products of a main industry are cedarwood oil and pine oils. The wood of the red cedar (*Juniperus virginiana*) contains a volatile oil known as "cedarwood oil". This oil is used extensively in the manufacture of perfumes, soaps and insect repellants. The oil is usually obtained commercially by distilling the sawdust and other wood wastes from the manufacture of cedarwood products.

Oil of turpentine constitutes the largest volume of oil produced in the United States. Its use as a solvent is well known. Important contributions to the conversion of the main components of the oleoresins from pine trees are continuously appearing in publications from the U. S. Naval Stores and private companies, such as Dow Chemical.

Conclusion

While this review is largely devoted to successful introduction of the essential oil industry into the United States, a long story could be written about the enterprises, small and large, which had to be abandoned. It is therefore fitting that a review written by Dr. Sievers of the U. S. Dept. of Agriculture (13) concludes its informative chapter on extraction of volatile oils from plant material by warning of the many pitfalls over optimism and lack of knowledge. The necessity of conducting small scale experiments is stressed before undertaking extensive operations when planting in a new region is planned. Thorough calculation of costs and correct appraisals of marketing conditions must be carried out. The fluctuating market value of the oils is determined not only by economic condition but also by varia-

tions in the quality of the oils. These variations might be due to unsuitable soil and climatic conditions, or improperly conducted extraction of the oils. Lower grade oils can be sold only at considerably lower prices, and carefully balanced cost estimates are upset. Studies have to be made on the possibility of by-products which sometimes make it possible to make some profit. Nevertheless one should realize that other industries often produce similar products, and here, too, a cold-blooded, sound, business calculation is better than a disappointment after losing an investment.

With these reservations constantly in mind it is safe to look at the other side of the medal and enjoy the activities of many workers in this field published in Chemical Digest, Reports of Oil and Drug Conferences, and in this journal.

Literature Cited

1. Aries, R. S. and Kidder, M. Production of thymol from California bay tree oil. Proc. Conf. Cult. Drug & Assoc. Econ. Plants in Calif. pp. 218–262. 1947.
2. Bourne, A. A. The creation of a new essential oil industry. Drug & Cosmetic Ind. **49**: 262–264, 271. 1941.
3. ———. Florida's lemon grass oil industry. Chemurgic Digest **4**: 148. 1945.
4. Frey-Wyssling, A. Die Stoffausscheidung der höheren Pflanzen. Mon. Gesamtgebiet Phys. Pflanzen und Tiere. 1935.
5. Guenther, E. Australian eucalyptus oils. Drug & Cosmetic Ind. August–October, 1942.
6. ———. The essential oils. Vol. 1: 85–213. 1948.
7. ———. The essential oils. Vol. 1: 15–77. 1948.
8. ———. Pine oleoresins. Proc. Conf. Drug & Ass. Econ. Plants in Calif. pp. 268–270. 1947.
9. ——— *et al.* Composition of gum turpentine of Torrey pine Jour. Am. Chem. Soc. **69**: 2014. 1947.
10. Hood, S. C. Possibility of the commercial production of lemon grass oil in the United States. U. S. Dept. Agr., Bull. 442. 1917.
11. Joseph, G. H. Citrus products—A quarter century of amazing progress. Econ. Bot. **1**: 415–426. 1947.
12. Sievers, A. F. The production of minor essential oils in the United States. Econ. Bot. **1**: 148–160. 1947.
13. ———. Methods of extracting volatile oils from material and the production of such oils in the United States. U. S. Dept. Agr., Bull. 16. 1928.

Utilization Abstract

Newsprint from Wheat Straw. "An event that may prove to be one of the greatest achievements in the history of chemurgy occurred recently when newsprint paper was manufactured for the first time in a commercial mill with wheat straw as its entire basic raw material".

This was accomplished by a process developed by The Kinsley Chemical Company of Cleveland, Ohio, and was carried out in September, 1948, at the Chemical Paper Manufacturing Company of Holyoke, Massachusetts. The expected greater utilization of farm residues resulting from this development should contribute much to relieving the present great demand for wood pulp in manufacturing the 21 million tons of paper produced annually in the United States. *Chemurgic Digest 7(10): 4. 1948*).

The Importance of Plant Classification in Hevea

More than 40 years work with one species of Hevea has resulted in great improvement in yield. An organized effort is now being made to select from numerous wild species living material offering new characters for disease-resistance and increase in yield.

RICHARD EVANS SCHULTES*

Introduction

Whenever a plant-utilizing industry is built upon a fragmentary understanding of the quality, potentialities and limitations of wild plant materials which could be made available to it from nature, then only a limited utilization of wild stock results and the progress which might otherwise be effectuated never materializes. Such is the situation in the rubber industry.

Hevea is one of the most recently domesticated of economic plants. Phenomenal improvements in strains of one species in it have been made during the last fifty years, but we may justifiably expect a fuller understanding of *Hevea* in its wild state to open up avenues of betterment and diversification which would astonish the scientific and commercial world. Studies and utilization of wild progenitors in cotton, sugar, potatoes, cereals and many other ancient cultivated plants have produced improvements in these crops, and comparable improvement might be achieved in *Hevea* through greater knowledge of all species in the genus and use of them in hybridization. Few of the specific and subspecific variants of *Hevea* have entered into the programme of the extensive rubber plantation industry which is based almost exclusively on material of *H. brasiliensis* originally from one small area—the Rio Tapajoz—of the vast Amazon Valley.

As a result of the short period—seventy years—of domestication of *Hevea*, the difficulty of travel where *Hevea* is native, and unavailability, until recently, of funds commensurate with the task of adequate exploration, we still lack intensive field studies upon which a definitive classification of the genus may be made.

Plant classification—or taxonomy—is a science. Many people, even today, do not understand its scope nor appreciate its aims. It has two general phases, the academic or theoretical, and the practical or applied. There never can be a sharp boundary between pure and applied science; the one is as important as the other to a scientist, even though one phase may interest him more than the other. While the numerous academic problems in *Hevea*, which only a taxonomic and phylogenetic study can solve, are of profound interest, I shall discuss in this brief article merely the practical value of taxonomy to a dollar-and-cents-conscious industry.

History, Distribution, Characteristics

Hevea is a genus belonging to the Euphorbiaceae, a world-wide family comprising some 7,000 species. *Hevea* leads all other genera in this economic-

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ally important family both from the point of view of financial investment and from that of influence on human progress. Native to South America and there confined to the Amazon Valley and several contiguous regions, *Hevea* inhabits an area three quarters the size of the United States.

Its taxonomic history began in 1775 when the French botanist, Aublet, described the genus from French Guiana. He called the type species *Hevea guianensis*. Knowledge of the genus advanced with painful slowness, however, until the field work of that most sacrificing of explorers, the Englishman Richard Spruce, whose collections from the Rio Negro of Brazil, made in 1852–53, provided the material for the description of eight additional species. The earliest synopsis of *Hevea* was published in 1873–74 by Mueller who recognized 11 species. Huber, working along the Amazon in Belem do Pará at about the turn of the century, greatly augmented the number of concepts until there were held to be 24 species. Later Pax classified the genus into 17 undoubted species. The most recent treatment is that of Adolpho Ducke who, after nearly half a century of field investigations, recognizes 12 species and numerous varieties and forms.

Although a relatively small genus, *Hevea* shows a most remarkable range of variation in the wild. Probably geologically a young genus still in a state of evolutionary flux, its classification often poses exasperatingly complex problems. There are a great number of subspecific variations, many of them biologically stabilized and with definite geographical correlations, others mere responses to environmental conditions. By intensive study of large populations in the wild state we may hope to gain a clear insight into the significance of variation in *Hevea*. Since cultivation often tends to induce additional and artificial variation, the only method is to track *Hevea* down in its native haunts. This must be done if we are to take advantage of the wide natural range of variability.

The rubber of *Hevea guianensis* and of *H. guianensis* var. *lutea* is often weak and of limited commercial application, but both the species and the variety show a most extraordinary range of variation. If fully understood taxonomically, these concepts might prove of unexpected significance in breeding work. They are jungle giants and prefer well drained

FIG. 1. The earliest fundamental investigations on the species of *Hevea* were carried out in the Rio Negro area of Brazil by that most self-sacrificing of explorers, the Yorkshireman Richard Spruce. (Drawn by Gordon W. Dillon from an old photograph preserved in the Gray Herbarium of Harvard University).

land above the flood level. Some representative variants grow as high as 6,000 feet altitude, and others inhabit uninviting rock and talus slopes which are almost devoid of soil. Although known to science before any other species of *Hevea*, *H. guianensis*, the most widely distributed species, remains today one of the most poorly understood concepts insofar as definition of its minor variants is concerned.

Hevea nitida is a large tree of flood-land jungles, but it may also occur in a varied form in light, highland forests. It yields a latex which coagulates into a sticky mass of no commercial value as rubber. Furthermore, the latex of this species, when mixed with that of other species, acts as an anticoagulant. Yet, in spite of its close relationship to *Hevea nitida*, the recently discovered *H. nitida* var. *toxicodendroides*, a tiny shrub-tree native to bare, dry and sun-baked sandstone hills where only a scrub vegetation can exist, yields a latex which gives a good rubber. Could we not expect the extreme resistance to drought and radiation, the apparent high resistance to leaf blight, the thick, leathery leaves, and the quality of rubber of this diminutive variety to be of value for breeding? *Hevea nitida* and its variants may be of extreme interest to the future breeder because, although it appears very distinct superficially, taxonomic studies indicate that it is rather closely allied to *H. brasiliensis*.

While *Hevea brasiliensis* yields the highest quality and quantity of rubber, the other species have unusual characteristics that might be valuable in experimenting for future plantation stock. The breeder and planter must consider not only yield and quality of latex and rubber; disease resistance; wound response; and other major factors. He must consider also a host of secondary points, such as thickness, softness and anatomical features of the bark as it affects tapping; resistance to wind; root system; utility as root-stock or crown stock in budding; characteristics of the foliage and branching; and innumerable other matters which are not always immediately obvious. The rubber industry must draw upon all of the forms which nature has already evolved. In the past, the experiments which have employed species other than *Hevea brasiliensis* have been few and limited, and opportunities of inestimable significance may thus have been overlooked.

The highly variable *Hevea Benthamiana*, growing usually in the most acidic of permanent black-water bogs, yields a very high-grade rubber. Some varieties and forms of it have very leathery leaflets and seem to prefer dry, sandy habitats. Is there not a hope that thorough study of this concept might produce interesting data for use in disease control or that the species might yield characteristics valuable for producing a clone which could grow in sites unfavourable for *Hevea brasiliensis*?

Other species and varieties might be pointed out as of prime interest to our study. Occurring in great numbers in the most swampy areas of the eastern half of the Amazon Valley, *Hevea Spruceana* is not tapped for rubber because it has a thin, non-coagulating latex. Little or nothing is known of the rubbers produced by *Hevea rigidifolia*, a very small tree of light, sandstone-hill forest and with extraordinarily coriaceous leaves adapted to long dry periods; nor of *H. microphylla*, a small forest tree whose seeds shed gently and not explosively as in all other species; nor of *H. pauciflora* and its numerous variants, inhabitants of rocky slopes and other inhospitable sites. And what may we expect when we are able to study stands of the diminutive *Hevea camporum*, known from only one incomplete herbarium specimen from granitic hills at the headwaters of the Rio Marmellos in Brazil; and when we can rediscover and introduce into cultivation *H. minor* from the Casiquiare?

Little really is as yet known of the minor variations of wild *Hevea brasiliensis* itself. Several varieties have been described, but the concept seems to be so variable that mass studies of wild populations must be made to appreciate the extent and significance of the differences.

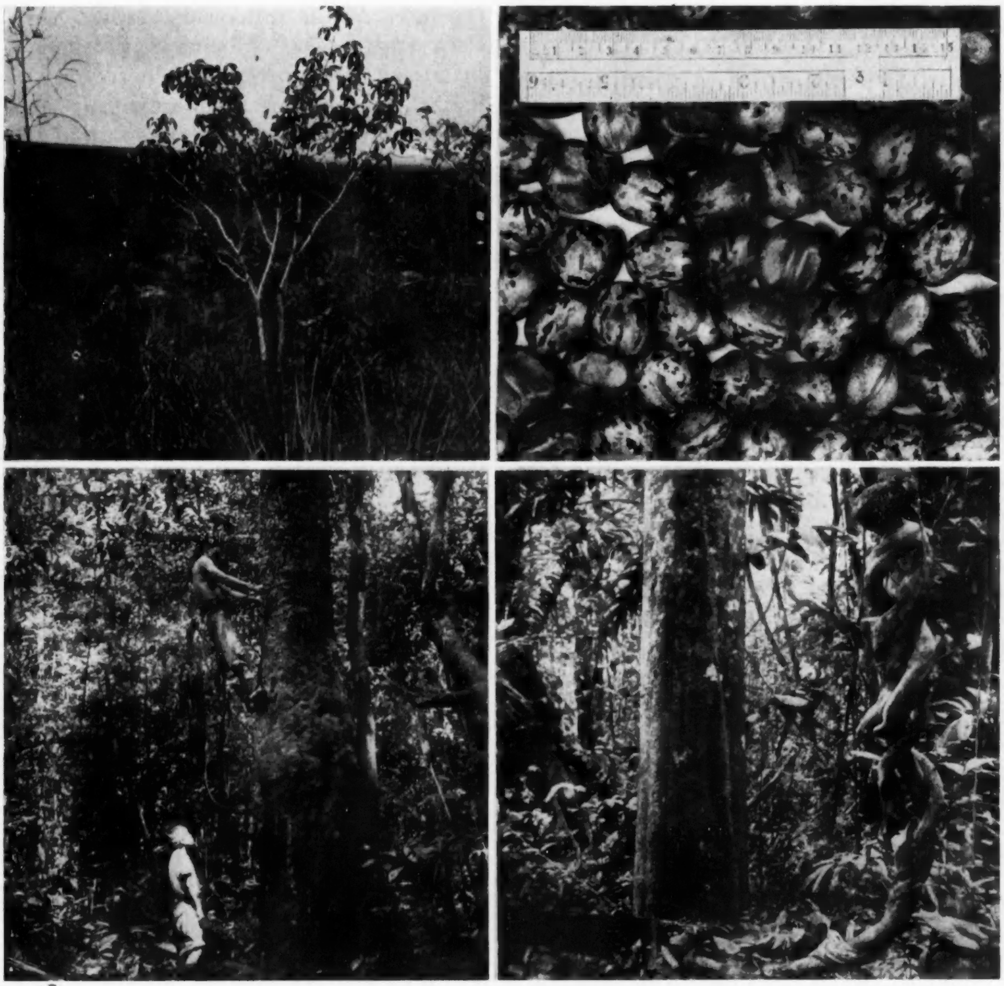

FIG. 2 (*Upper left*). *Hevea* trees may be tremendous giants of the jungle, such as *H. brasiliensis* and *H. guianensis* which often reach a height of 140 feet; or they may be, like *H. nitida* var. *toxicodendroides* in the illustration, diminutive shrubs or semi-prostrate bushes native to open, xerophytic, sandstone mountain-tops.

FIG. 3 (*Upper right*). The collection for nurseries of tons of seed of *Hevea brasiliensis* has afforded botanists an opportunity to study the variation in seeds from native populations of this species. The figure shows one type of seed of *Hevea brasiliensis* from Leticia, Colombia.

FIG. 4 (*Lower left*). An intensive search for outstandingly superior wild rubber trees has been in progress for several years in the Amazon Valley. Suitable branches are cut from selected trees and are sent to central nurseries to provide budding material. The ascent of an enormous tree of *Hevea brasiliensis*, shown in the illustration, is a difficult task because of the height and corpulence of the tree, as well as the many spiny ant-infested air-plants which clothe a great part of the trunk.

FIG. 5 (*Lower right*). Unlike many species of *Hevea*, *H. guianensis* is native to high land which is not subject to four or five months of deep inundation each year. This species is one of the most majestic trees of the high-land Amazonian jungle where it sometimes reaches 125 feet in height.

Recent Investigations

During the last five years the United States Department of Agriculture has carried out, through its Division of Rubber Plant Investigations and in cooperation with the governments of Brazil, Colombia and Peru, an ambitious programme of jungle selection of outstanding wild individuals of *Hevea* which show high yield and disease resistance. It has also encouraged cytogeographic and taxonomic studies. This work has necessarily been concerned chiefly with *Hevea brasiliensis*. But whenever fortune has permitted, material has been selected from as many of the other species, varieties and forms as possible. A significant living collection is being assembled in order that we may have at hand a museum of the wild representatives of *Hevea* for use in scientific programmes. This collection includes *Hevea Benthamiana;* several variants of *H. guianensis* and its variety *lutea; H. nitida;* and a number of others. Recently the extremely rare *Hevea rigidifolia*, not seen since Spruce collected it nearly a century ago on the Rio Negro, has been rediscovered in several localities of the same area. Further explorations may even turn up species as yet unknown.

Thousands of trees have been studied; tons of wild seeds have been gathered: chromosome counts have been made of hundreds of wild trees; and thousands of herbarium specimens, notes and photographs of numerous species of *Hevea* have been prepared. It is fully realized that seemingly academic studies are highly practical, not only to plant breeders but also to chemists. A clear classification of *Hevea* may help the chemist understand differences in properties of the latex of the numerous species, varieties and forms. Chemical differences in latices, while often influenced by ecological factors, are fundamentally correlated with the genetical make-up of the plant.

This is the first time in history that such an extensive programme has been possible with *Hevea*. The success it has met with is due largely to the sustained interest of the cooperating Latin American governments. We feel that we are finally at the dawn of a better comprehension of what *Hevea* really is and of how the genus is constituted. Only continued exploration, however, will enable taxonomy to prepare for science in general and for the rubber industry in particular a final blue-print of this most fascinating of plant groups.

The remarkable expansion of the elastomers of the so-called ''synthetic rubber'' industry is creating a demand for rubbers and rubber-like substances of all types for use as ''fillers'' or ''softeners''. We who are engaged in plant exploration and classification must be on the alert, for perhaps one of the humbler species of *Hevea*, today passed by because its latex is intrinsically of no commercial value, will one day assume an exalted place as producer of a superb softener for some as yet unknown elastomer.

At the present time, in our really incipient stage of knowledge of what the potentialities of the rubber trees of the genus *Hevea* are, we continually refer to the available taxonomic work, incomplete as it is, for any fundamental step in plant-breeding or selection. Should we not strive to provide a more satisfactory and complete classification as the first step in our programme for an overall betterment of the industry?

Roselle—*A Potentially Important Plant Fiber*[1]

Not yet exploited in the Western Hemisphere, this jute-like African fiber possesses commercial possibilities and is obtained from a plant that furnishes also edible fleshy calyces and oil-containing seeds.

JULIAN C. CRANE[2]

Introduction

The roselle plant (*Hibiscus Sabdariffa* L.) is used principally for its bast fibers and for its fruit, the latter being utilized for making jelly and preserves. The silky, soft and light-colored fiber obtained from this plant has practically the same chemical and physical properties as jute (*Corchorus capsularis* L.) fiber and, therefore, offers a very satisfactory jute substitute.

At the beginning of the second World War roselle attracted considerable attention with respect to its being utilized as a quick source of soft fiber for the manufacture of burlap and other fibrous articles. Consequently a comprehensive review of the literature, presented here, was made in order to assemble the world-wide information dealing with the roselle plant and its products. Although statements made in some cases are rather confusing and contradictory, one must remember that the data here reported have been compiled from widely separated locations that have greatly different soil and environmental conditions.

Considerable confusion exists with respect to literature references, several of which, especially from this hemisphere, deal with "roselle", although it has been determined that the plant material discussed was actually kenaf (*Hibiscus cannabinus* L.), a close relative of roselle (9). Although plants of these two species are apparently quite similar regarding cultural and environmental requirements, our limited experience with roselle in this hemisphere precludes comparative evaluation of the material presented here with that which has been published on kenaf (10).

History

In a study of the history of roselle, Wester (46) found that the first published account of the plant was made by the Flemish botanist, M. de L'Obel, in 1576 (31). Wester believed that the species was probably brought westward from India by the Mohammedans who invaded India several centuries before the plant was described by M. de L'Obel. That the plant was from the beginning known by the name "Sabdariffa", a Turkish word, according to Drury (13, p. 252), lends color to this belief. Use of the leaves for greens and reference to its cultivation for fiber first appeared in 1687 (23).

Roselle was reliably reported from the Western Hemisphere at the beginning of the eighteenth century, at which time it was in cultivation (46). Wild plants of *Hibiscus Sabdariffa* that occur in the American tropics would seem to have escaped from cultivated fields. This indicates that the species is not indigenous to the American tropics but is probably of Old World origin.

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Probably the first roselle, the tall, unbranched type (var. *altissima*), cultivated for fiber in the Western Hemisphere was grown in Cuba in 1919 (5). The seed for this crop was sent by P. J. Wester from the Philippine Islands to the Cuban Agricultural Experiment Station.

We are led to believe that the culinary uses of the calyces of this species were first recognized in Jamaica in 1707 (41 p. 224), where, it was stated, "the capsular leaves are used for making tarts, jellies, and wine for the treatment of fevers and hot distempers, to allay heat and quench thirst". It is reported that the species was introduced into Florida from Jamaica, probably during 1870 to 1880, and that it was first grown in California about 1896 from seed imported from Australia (46). It is rather odd that roselle was introduced into the Philippine Islands from the Western Hemisphere (Trinidad) in 1905–250 years after it was known in Java. Considerable interest in roselle developed in Florida and California during the early 1900's with respect to the use of the enlarged calyces in jam and jelly making.

Use of roselle for commercial purposes was not recognized until the middle of the last century when it was found to be of value as a source of fiber (40). That the plant attracted but little attention until a comparatively few years ago is shown by the fact that it was not included by A. de Candolle in his "Origin of Cultivated Plants", published in 1882.

Roselle appears to have been a horticultural crop of considerable importance in Queensland, Australia, in 1892, since there were two preserving factories in operation for utilization of the calyces (46). Roselle jam is reported to have been shipped to Europe in large quantities in 1896. Later this industry must have suffered a serious decline, for the Queensland Department of Agriculture Report for 1909 states that there were only 1.6 hectares (four acres) of roselle producing edible commodities.

Description and Nomenclature

Roselle, which produces enlarged edible calyces and the roselle fiber of commerce, is an annual plant belonging to the large family Malvaceae. It is closely related to several genera containing fiber-producing plants, *e.g.*, *Abutilon*, *Sida*, *Malva*, *Althaea*, *Urena* and *Lavatera*. Its most important relative from a commercial standpoint is cotton (*Gossypium* spp.). Other species of economic value related to roselle include okra (*Hibiscus esculentus* L.), the young fruit of which is commonly used as a vegetable; kenaf (*H. cannabinus*), cultivated for the fiber obtained from the inner bark; and some used for ornamental purposes, of which the Swamp or Rose Mallow (*H. moscheutos* L.) is a common example.

Roselle has been variously called "sorrel", "red sorrel", "East Indian sorrel plant", "thorny mallow" and "various-leaved hibiscus". The assumption by Royle (40) that the name "roselle" is a corruption of the French word "oseille", (the equivalent of the English word "sorrel"), seems well justified. It has been spelled "rouselle", "rosella" (Spanish) and "rozelle". In the commercial trade of some parts of the world the calyces of the edible types of *Sabdariffa* are called "karkade flowers". In India the plant is known under the vernacular names "mesta", "patwa", "lal ambari" and "kempu". The fiber has been called "India rosella hemp", "rosella fiber", "rosella hemp", "rozelle hemp" and "Pusa hemp".

Most of the statements and descriptions concerning roselle refer to a plant with red stems and calyces, the latter being used for culinary purposes. In some articles mention is made of a form with a green or whitish calyx, but no descriptions were given until not only the red

and green varieties but also two intermediate forms were differentiated at Pusa, India (25). These intermediate forms are partly red, but in each the localization of the color is different. A form of roselle having light-green stems and leaves with straw-colored or whitish calyces was recorded by Hughes (26, p. 204) almost 200 years ago. How long it had existed before that time is not known.

Varieties

Hibiscus Sabdariffa may be divided into three main groups (see Table 1) on the basis of plant coloration: (*a*) plants of which the stems, petioles and calyces contain a red pigment throughout, which gives the brilliant red color characteristic of all food products made from plants of this type; (*b*) plants lacking this red pigment, all parts of the plant being greenish and the calyces straw-colored or whitish; (*c*) plants which are intermediate between the green and the red types; that is, the stems, petioles and calyces contain red pigment only in certain localized spots or splashes.

The type of plant with deep red coloration is decidedly the most useful for culinary purposes, both because its color is attractive and because the calyx is less fibrous and harsh than in the other types.

Hibiscus Sabdariffa might be further divided on the basis of growth habit into two groups: a tall-growing, unbranched form, the type of plant desired for fiber production; and a shorter, much-branched form, generally used for its edible calyces and leaves. The difference in growth habit is so pronounced in this species that Deshpande (12) believed that the fiber variety described by Wester as *altissima*—the tall unbranched form—might be a different species. He made successful intervarietal crosses between *H. Sabdariffa* var. *altissima* and the short much-branched varieties selected by Howard and Howard (25), in order to determine whether there is an affinity between the two forms.

Although the culinary and fibrous uses of roselle have been known for a considerable length of time, the division of the species into different varieties has been comparatively recent. No varieties of roselle appear to have been selected until the culinary variety Victor was isolated and named in 1907 (45). This variety originated among a number of seedlings grown at the Subtropical Laboratory, Miami, Florida. The culinary variety Rico was named and illustrated for the first time in 1912 (47). Two other culinary varieties, Archer and Temprano, the latter being originated at the Lamao Experiment Station in the Philippines, were described by Wester (48) in 1914. The Temprano, an early maturing red variety, was selected from a planting of the Victor variety, while Archer, characterized by all parts of the plant being greenish or whitish, was originated from seed received from A. S. Archer, of Antigua, British West Indies.

Howard and Howard (25) in 1911 selected four varieties of roselle and found them to breed true. With the exception of a slight difference in the form of the calyx in *H. Sabdariffa* var. *bhagalpuriensis* and differences in color, these workers found the four varieties to be absolutely identical in all "morphological and agricultural characters". They flowered at the same time, grew to the same height and were equally robust. Howard and Howard did not state which of these varieties was best suited for fiber production, but Youngberg (51) found the green-stemmed varieties to contain 4.75 percent more fiber than the red varieties.

In describing the type of plant grown in India and the material from which they selected the four varieties, Howard and Howard (25) stated that the height of the plants varied with the cultivation practice and in some cases reached ten feet. They gave the following botanical

TABLE 1

ECONOMIC VARIETIES OF *Hibiscus Sabdariffa*

Variety	Use	Habit	Color			
			Stem	Leaf	Calyx	Corolla (withered)
altissima (48) a[1].	fiber	tall,[2] unbranched	red	green with red veins	red	......
b[1].	fiber	tall, unbranched	green	green	green	......
c[1].	fiber	tall, unbranched	green, with red patches above and below leaf scars	green	green	pink
bhagalpuriensis (25)	fiber	short,[3] branched	green, with some diffused red color; red patch above leaf scars	green	bright green, with red splashes	orange-pink
intermedius (25)	fiber and fruit[4]	short, branched	green, with some diffused red color; red patch above and below leaf scars	green with some reddening on upper surface of veins	yellowish green; red spot on mid-nerve	yellow
albus (25)	fiber and fruit	short, branched	green	green	yellowish-green	yellow
ruber (25)	fiber and fruit	short, branched	dark red	green with red veins	red, gland on mid-nerve greenish	deep orange-pink
Archer (48)	fruit	short,[5] branched	green	green	green	......
Temprano (48)	fruit	short,[6] branched	light red	green with reddish veins	light red	......
Rico (47)	fruit	short, branched	dark red	green with reddish veins	dark red	......
Victor (45)	fruit	short, branched	reddish	green with reddish veins	reddish	......

[1] For convenience in this paper, the writer has divided the *altissima* variety into a, b and c types as indicated in this table.
[2] Sometimes exceeding 14 feet, depending upon soil and environmental conditions.
[3] Generally speaking, not exceeding seven feet.
[4] Enlarged edible calyces.
[5] Frequently exceeding 1.6 meters (5.2 feet).
[6] Rarely exceeding 1.25 meters (4.1 feet).

description of the species *Hibiscus Sabdariffa,* together with the major differences among the four varieties:

Shrub erect, annual. Stem glabrous, unarmed but with emergences at intervals, much branched with long branches arising near the base. Stipules generally simple and linear, sometimes bilobed. Leaves lobed, upper ones simple and lanceolate, with a pulvinus at the base of the blade, and a gland on the midrib of the leaf; margin serrate; petiole often with a line of hairs on the upper surface. Peduncle solitary and axillary. Epicalyx united at the base and adnate to the calyx; bracteoles 8–12, linear. Calyx connate below, free above; sepals 5–7, accrescent, fleshy, with a gland on the midnerve of each. Corolla yellow, spreading; aestivation imbricate. Capsules ovoid, pointed, villous, shorter than the calyx. Seeds reniform, subglabrous.

1. Var. *ruber*
   Stem and petiole entirely red, pulvinus red, calyx red, flowers on withering turn pink.
2. Var. *albus*
   Stem and petiole green, pulvinus green, calyx yellowish, flowers on withering remain yellow.
3. Var. *intermedius*
   Stem and petiole green with some red, pulvinus red, calyx yellowish green, flowers on withering remain yellow.
4. Var. *bhagalpuriensis*
   Stem and petiole green with some red, pulvinus green, calyx green with red splashes, slightly more obtuse and more twisted than in any of the other three varieties, flowers on withering turn pink.

Up to this point, all the varieties described belong to the type of *Hibiscus Sabdariffa* which is characterized by plants that are bushy and branch profusely, the branches arising from the base of the stem. Not until 1914 did Wester (48) describe the fiber-producing *H. Sabdariffa* var. *altissima.* This variety originated from seed received by the Philippine Bureau of Agriculture from the Gold Coast, West Africa, in 1911. Wester stated that the plant evidently had no economic value in the Gold Coast, for the correspondent forwarded the seed to him with the remark that it was an "interesting plant". Wester noted that plants grown from this seed "in some respects differ radically from all other forms examined by the writer. They differ from each other in that one kind belongs to the red type of roselle while the other form is intermediate between the red and the green".

A report (18) in 1912 states that botanical specimens of a species of *Hibiscus,* which had been grown in the Gold Coast, West Africa, for its fiber were forwarded to the Kew Botanical Gardens for identification. The specimens were identified as a variety of *H. Sabdariffa,* but were "not the form usually cultivated". Whether this plant material was the source of the seed from which Wester selected the variety *altissima* is not known. This tall unbranched form of *H. Sabdariffa* was, however, unheard of until after he named and described it in 1914.

In addition to the red and intermediate forms of the fiber variety *altissima,* there appears to be also a green-stemmed form, since Koch (28, 29), speaking of *altissima,* stated that "both red and green varieties grow 4 to 5 meters (13 to 16.5 feet) high with slender stalks and no branches". Although he may have overlooked the fact that the "green variety" might have contained small amounts of localized red pigments and, therefore, would be the intermediate form as described by Wester (48), Deshpande (12) and Abdur Rahman Kahn (2), a green form of the *altissima* type also seems likely to exist as it does in the shorter much-branched type of *Sabdariffa.*

From the obversations made by many students, the tall-growing variety *altissima* appears to be characterized by its non-branching growth habit (2, 12, 48) as contrasted with the other varieties which have a comparatively short and much branched growth habit (2, 45, 47, 48). Under certain conditions, however, the variety *altissima* has been observed to

branch considerably. Some workers have observed that the variety branches somewhat when widely spaced or when growing next to drainage ditches or at the end of the rows (33, 43, pp. 48–49). Nevertheless, from the studies made on the plant by various workers, the conclusion may be drawn that the variety *altissima* can be given definite varietal rank.

Although nine varieties of *H. Sabdariffa* have been selected and named by Wester (45, 47, 48) and Howard and Howard (25), considerable synonymy is believed to exist in their varietal designations. For example, the culinary varieties Victor, Rico and Temprano, selected and named by Wester, are apparently synonymous with the variety *ruber*, named by the Howards. The Howards in 1911 were evidently not aware of the fact that Wester had named and described the culinary variety Victor in 1907, since they made no reference to this variety. Further, the belief is that the culinary variety Archer, a green-stemmed type selected by Wester, is the same as the green-stemmed variety *albus*, selected and named by the Howards.

Cytogenetics

In order to study the affinity of var. *altissima* with the varieties named by Howard and Howard (25), a number of intervarietal crosses were made (12). From this work strains were obtained combining the tall unbranched habit of var. *altissima* with the smooth stem of the other *Sabdariffa* types. Deshpande (12) crossed the *altissima* variety with varieties *albus* and *ruber* and also with some types of *H. cannabinus*, and showed that the average percentage of capsules set in the former was 53.8, all the capsules having viable seeds, whereas that in the latter was 44.4, none of the capsules having any viable seeds. These results are readily explained by the fact that, according to Medvedeva (34), the two species have different chromosome complements, *H. cannabinus* possessing 36 and *H. Sabdariffa* 72, respectively. He stated that all the crosses between the varieties and geographical races of *H. cannabinus* belong to the type of "congruent" crosses and are successful, but that, on the contrary, owing to the extreme diversity of karyotypes in the genus *Hibiscus*, the outlook of interspecific hybridization is not promising.

Anatomical Portion of the Plant Used for Fiber

The fibers obtained from roselle are spoken of botanically as "bast cells" and are 1.2 to 3.3 millimeters long and from 0.01 to 0.03 millimeter wide (35). They form the principal part of the fibrous bark, or the bast layer. These cells are contained in a layer just under the bark of the plant and outside the central woody cylinder and thin cambial tissue. Their ends overlap each other so as to form, in mass, a filament. Cells of this type give strength and flexibility to the stem, and the extracted bundles of these cells form the filamentous product known commercially as fiber.

Photoperiodic, Climatic and Soil Requirements

Roselle has been shown to exhibit marked photoperiodism (4, 27, 32). McClelland (32) found that when the length of daily illumination was shortened to 11 hours, roselle plants developed buds four weeks after planting, produced large red fruit in ten weeks, although the plants were only five inches tall, and matured seed in 14 weeks. These plants remained about five inches tall. On the other hand, plants that were give a daily illumination of 13.5 hours for $5\frac{1}{2}$ months attained a height of 36 to 45 inches, and none showed a tendency to blossom. These plants were still growing vigorously when those under the artificially shortened day, having fruited, were dying.

As roselle is sensitive to frost, subtropical or tropical locations seem to be the ideal environment for the plant. Because, regardless of the date of planting, the plant does not flower and fruit in the United States until the short days of late fall or early winter, production of roselle fruit in temperate zones seems difficult to achieve, unless frost-free conditions enable the plants to grow through December (27). For fiber production, on the other hand, it is highly desirable to have long clean stems free of branches or fruiting stalks which interrupt the continuity of the fiber. Plant material of this kind, therefore, may be obtained only when the plants have grown under comparatively long light days for three to four months. Since production of the finest quality fiber is dependent upon an environment that promotes continuous and rapid growth of the plant, 18 to 20 inches of rainfall during this three- to four-month period would seem to be desirable (6).

For fiber production the plants should not be subjected to strong winds or prolonged foggy weather, since the quality of the fiber is best when the plant is uninterrupted in its growth (6). It has been noted that a cessation of growth for only seven or eight days was sufficient to exert an unfavorable influence on the quantity and the quality of the fiber produced. Roselle appears to do equally well from locations at sea level to an elevation of 2,000 feet (38).

Roselle is not very exacting in its requirement with regard to the physical properties of the soil, except that it should be permeable, not very compact and not subject to flooding (6). In Ceylon (21) roselle has thrived on heavy loam soils capable of retaining a good supply of moisture. Laterite soils and light soils deficient in humus have proven to be unsuitable for satisfactory growth (22). In order to hasten maturity of the fruit, Beattie (3) recommends avoiding extremely rich soils or application of nitrogenous manures, since these stimulate development of large plants at the expense of flower production.

Cultural Requirements

The cultural requirements of roselle have not as yet been determined by extensive agronomic studies. Most of the information pertaining to the culture of this plant is based primarily on small plantings and limited observations by various individuals. One point, however, agreed upon by all writers is that preparation of the seedbed should be given special attention and the soil plowed rather deeply. Because of the comparatively long taproot of roselle, the soil should be plowed to such depths as to stimulate and aid the growth of these roots. The seedbed should be carefully prepared to aid in a uniform germination of the seed and subsequently a uniform stand of plants, which is of great importance in fiber-crop production. Not only is a uniform time of maturity desirable for the plants of a given area, so that they can be harvested and defibered at one time, but also desirable is uniform quality of the fiber.

Fertilization. A number of workers have studied the effects of application of fertilizers on the growth of roselle plants and the production of fruit and fiber. In the Philippines (39) it was found in all cases that such applications gave favorable effects on the height of plants irrespective of the fertilizer formulae used. Best results were obtained when nitrogen-bearing fertilizers were applied in combination with smaller amounts of potassium and phosphorus.

Ettling (15), Koch (29) and Dekker (11), all working in Java, pointed out that roselle was greatly benefited by the use of green-manure crops as a means of building up the soil preparatory to planting. They recommended the use of *Mimosa invisa* as a leguminous green-

manure crop, provided it is turned under before it starts to mature its seeds. On the other hand, commercial fertilizers were also used with success, the greatest response being obtained from ammonium sulphate at the rate of 450 pounds per acre (11). These results are corroborated by the work in Africa and Java of Campese (6) who observed that nitrogen and potassium are the two elements that roselle needs in rather large quantities. He recommended application of manure at the rate of 8,000 to 18,000 pounds per acre or a commercial fertilizer supplemented with a green-manure crop.

Thus far no conclusive proof has been given as to whether a rotation of crops is necessary in growing roselle; but, since the plant is subject to attack by the root-knot nematode (*Heterodera radiciola*), a rotation is probably advisable (49). Campese (6) recommended that roselle be worked into a rotation program; that is, he suggested that it be preceded by a leguminous green-manure crop and followed by corn.

For fruit production Wester (45) stated that stable manure should be used sparingly and should be supplemented by phosphates and fertilizers containing potash. He found that an excess of ammonia in the soil encouraged the development of large plants at the expense of fruit production. A commercial 4-6-7 fertilizer gave good results, and he stated that best results were obtained in Florida when the organic forms of nitrogen were applied at the rate of 1,000 to 2,000 pounds per acre. Fertilizers in which inorganic sources of nitrogen were used did not give such high yields.

Time and Distance of Planting. The time of planting roselle, particularly for fiber, is one of the most important factors in its production. In view of the fact that the plant is sensitive to changes in length of day, it is readily understood that the best time for planting in a location of a given latitude might not be successful in another location of a different latitude. It is generally agreed (6, 28, 36) that roselle should be planted at the beginning of the rainy season. Likewise a daily illumination of approximately 13 hours for three to four months following planting is necessary in order to prevent flower bud initiation until after the plants reach sufficient height to insure adequate yields of fiber per area of land. In other words, in order to obtain long clean stems free of branches and fruiting stalks which interrupt the continuity of the fiber, planting should be done at the beginning of a three or four month period characterized by 18 to 20 inches of rainfall with day lengths of not less than 13 hours.

Experiments in Florida, Hawaii and the Philippines (47, 3) have shown that roselle normally begins blooming the latter part of September or the first of October. For fruit production, therefore, the seed may be sown any time after the first of February but before the middle of May in the Northern Hemisphere and before the corresponding time in the Southern. If planted later than the middle of May, the plants do not have sufficient time to develop vegetatively before flowering and fruiting begins.

Distance of planting is of great importance to the quality of fiber produced (15). Work in Java and Africa (6, 11, 15, 38) has shown that the best quality fiber is obtained from plants spaced six to 8 inches between rows and five to nine inches between plants in the row, using about 18 pounds of seed per acre. In Malay (22, 43), however, drilling in rows three to six inches apart at a rate of 20 to 25 pounds of seed per acre is recommended.

Broadcasting the seed has been tried in several instances, but this practice is not recommended because of the uneven stand of plants obtained and lack of uniformity in the fiber produced.

Since roselle is harvested for fiber when the plants begin to bloom, a separate planting for seed is necessary. At fiber-harvesting time the practice has been, in many places, to merely leave uncut a portion of the field as a source of seed. Harvesting seed from a planting originally intended for fiber, however, is difficult and costly. In addition, much lower yields of seed are obtained than from a planting made at the proper time and having a planting distance especially for seed production.

between rows, depending upon soil fertility, supply of moisture and the time of year when the seed is sown, the earlier sown seed being planted at the greater distances. In Florida (3) seedlings started indoors are re-planted in the open at the same time as tomatoes in rows four feet apart and from three to four feet apart in the row.

Recommendations regarding planting distances used in various parts of the world for fiber, seed and fruit production are summarized in Table 2.

TABLE 2

A SUMMARY OF DIFFERENT PLANTING RATES RECOMMENDED BY STUDENTS OF ROSELLE PRODUCTION

Author	*Country*	*Distance between rows*	*Distance between plants*	*Seed required per acre*
		Inches	*Inches*	*Pounds*
For fiber				
Koch (28)	Java	12	4 to 5	....
Ettling (15)	Java	6 to 8	5 to 9	18
Henning (22)	Malay	3[1]	....	25
Serdang Exp. Plant. (43)	Malay	3[1] to 6	....	20 to 25
Campese (6)	Africa and Java	8	6	14 to 16
Dekker (11)	Java	6 to 8	6 to 8	19 to 23
Prat (38)	Africa	5 to 9	6 to 8	13 to 18
For seed				
Ettling (15)	Java	30	15	....
Campese (6)	Africa and Java	31	20	....
Dekker (11)	Java	30 to 40	30 to 40	.8 to 1.6
For fruit				
Wester (49)	Philippines	4.5[2] to 9	3[2] to 7.5	....
Beattie (3)	Florida	4[2]	3[2] to 4	....

[1] Drilled. [2] Feet.

For the production of seed it is generally agreed that the distance between plants should be somewhat greater than for fiber production. In Java the planting distance varies from 30 inches between rows and 15 inches between plants to spacings of 30 to 40 inches on a square (11, 15). Similar treatment is recommended in Africa where plants are spaced 20 inches in the furrow with 32 inches between furrows (6).

For fruit production in the Philippine Islands (49), roselle is planted in hills 3 to $7\frac{1}{2}$ feet apart with $4\frac{1}{2}$ to 9 feet

Methods and Time of Harvesting. Roselle is such a rank grower that it soon shades out weed competition. Generally plantings made for fiber production require no cultivation or other care from the time of seeding to harvest. For seed and fruit production, where the rows ane spaced farther apart, one or two cultivations may be necessary, depending upon seed bed preparation and weed population.

Some diversity of opinion exists as to the proper time for harvesting roselle for fiber. The recommended harvesting

time has varied from the stage at which the plants first started to bloom until seed maturity. The results obtained by workers in Java and Malay (11, 43) indicate that the best time for harvesting is at the end of three or four months or "before large flowers have appeared". Henning (22), on the other hand, affirms that the best time for cutting is just after the plants have flowered. Other workers have observed that if harvesting is delayed until after blooming, the plants become woody, the fiber is of poor quality, and the stems are much more difficult to ret (6, 22).

As far as yield of fiber is concerned, the longer the plants are allowed to grow, the greater is the quantity of fiber obtained per unit of area. Michotte (36) presents the following data from Java, which clearly illustrate this point:

TABLE 3

RELATION BETWEEN DURATION OF GROWTH AND FIBER YIELD IN ROSELLE

Plants cut after	*Yield in dry fiber, pounds per acre*
100 days growth	1,338
135 days growth	2,230
165 days growth	2,677

Even though a progressive increase in yield of fiber is obtained with a progressive increase in length of time that the plants remain in the field, Campese (6) noted that there was a progressive decrease in quality of the fiber produced. He stated that the plants should be cut between three and four months after planting to obtain the best quality fiber.

There appear to be two methods of harvesting the plants. They may be pulled up by the roots or cut off at the ground level. The latter method seems preferable in that it requires less effort, and the root systems remaining in the ground constitute a source of organic matter.

Some authors (15, 25, 33) have declared that the cut stalks should be tied in bundles of 25 to 30 preparatory to retting; others (22, 28, 43) have asserted that a more economical and satisfactory way is to strip off the cortex in the field and tie it in bundles for retting.

The slow and tedious process of harvesting roselle by hand in this hemisphere is impractical and uneconomical because of comparatively high wage rates. Since the habit of growth and size of the roselle plant are similar to those of kenaf, mechanical harvesters used for harvesting the latter plant should undoubtedly prove successful for roselle. Harvesting investigations on a commercial scale, using a modified hemp harvester-binder, have demonstrated that a crop of kenaf planted in eight-inch drills rows, which had grown to a height of 10 to 12 feet, could be cut and bundled at the rate of an acre per hour (10).

The seed capsules of roselle mature progressively from the lower to the upper portion of the plant. For seed production the plants are cut when the seeds at the lower and middle portion of the bearing area are fully mature. The common method of harvesting roselle for seed is to cut the plants by hand at the stage just mentioned and to shock them in the field for several days, so that seed at the top portion will have time to mature and cure before threshing. If harvesting by hand is delayed until all the seed capsules on the plant have reached maturity, then considerable seed is lost by shattering, especially from the lower portion of the seed-bearing area. To thresh roselle, the dried plants have usually been placed between large pieces of canvas and then beaten or flailed with long poles, after which the seed has been cleaned by winnowing. Here again, if this crop is to become of commercial importance in this hemisphere, mechanical methods for harvesting and cleaning seed will have to be developed.

The edible fleshy calyces mature very

rapidly and are ready to harvest within 15 days after blossoming (49). The fruit is gathered when the calyces are plump, crisp and of a deep red color, and before any woody matter has formed (3). If the calyces are picked promptly after attaining full size, the plants continue to bloom longer, the harvest is prolonged and the yield is materially increased.

Fiber Extraction

There are various means of extracting the fiber from roselle stalks, all of which involve retting in water, except when power-driven decorticating machines are used. No consistent agreement was found in the literature on the best retting procedure for roselle but, generally speaking, most workers (11, 22, 43) agree that the stalks are sufficiently retted after 8 to 10 days. The work of Campese (6) and experiments in the Philippines (1) showed that the fiber can not be washed until after 14 or 15 days, and Wester (45) held that the material should be retted for 15 to 20 days. Horst (24) reported that freshly cut stalks required 21 days to ret, whereas partially dried stalks retted well in 15 days.

The variation in the length of the retting period, as reported in the literature, is caused, no doubt, by the greatly divergent environmental conditions under which the plants were grown, the differing stages of maturity of the plants at the time of harvesting, the different kinds (fresh, stagnant, *etc.*) and temperatures of the retting water used, and the many other differing inter-relationships that were not controlled or considered.

The retting process is complete when the bark separates easily from the central woody cylinder and the fiber washes clean. At this stage the bundles of stalks are broken open and the fiber is stripped and cleaned by hand, after which it is dried in the sun. A skilled worker can strip 80 to 100 pounds of dry clean fiber in a day.

Extraction by mechanical means apparently has not received attention, since there is no reference to the subject in the literature. The similarity between the roselle plant and the kenaf plant, as discussed above, would indicate that roselle might also be defibered successfully by machine. Large henequen—(*Agave fourcroydes* Lem.)—decorticating machines have been used in Cuba to process kenaf (10). These machines scrape away the central woody cylinder, water and waste material from the stalks, leaving the clean fiber which is then dried in the sun.

Yields. The yield of dried fiber per unit of area, as reported in the literature, varied widely according to the soil and climatic conditions where the crop was grown. The percentage of extracted fiber from the stalks ranged from 2.3 percent (28) to 7.9 percent (50). In general, the average yield per acre seemed to be about 1,500 pounds of dried fiber. In West Africa (18), yields of 600 pounds per acre were reported; in Ceylon (7), 1,970 pounds per acre; Dekker (11), in Java, reported yields of approximately 1,338 pounds per acre, while Michotte (36) reported yields in British Malay ranging from 1,115 to 3,123 pounds per acre.

The only reference in the literature regarding seed yield is that of Campese (6). He reported that an acre of roselle cultivated for seed produced only 357 pounds of seed, enough to plant about 18 acres for the production of fiber if seeded at the rate of 20 pounds per acre.

Wester (49) stated that 5,000 to 7,000 pounds of roselle calyces may be obtained per acre from plantings made during May. He noted that with good varieties and under favorable conditions these yields may be nearly doubled. Data from Hawaii (49) bear out this fact in that, grown as an intercrop with

rubber, roselle yielded 15,000 pounds of fruit per acre. In Florida the yield varies with the region and conditions of growth, but may be anywhere from three to 12 or 15 pounds per plant (3).

Uses and Properties of Roselle

Fiber. As to the utility and quality of roselle fiber, there is considerable disagreement among the various authors reporting on the subject. This, however, is to be expected, since the conditions under which the plants were grown and the methods of preparing the fiber differed greatly. Campese (6) maintains that well-prepared roselle fiber can be woven into bed clothing, table linen and other articles for which cotton is used. The fiber is twice as strong as jute, and ropes and cables made of roselle, according to him, were preferred by the "navy and merchant marine" because they deteriorated little when wet and did not rot if left for a long time in salt or fresh water. Fishing nets made from this fiber, he said, were also extremely resistant and broke only under great strain. He stated that fiber from young plants is suitable for the manufacture of paper. Ettling (15) and Prat (38), discussing the characteristics of roselle fiber, state that it is twice as strong as jute, is very resistant to sea water, and can be spun without difficulty.

Of a sample of *Hibiscus Sabdariffa* fiber from the Gold Coast, West Africa (18), the Imperial Institute in London made a chemical analysis and presented the following data in comparison with extra fine jute fiber. The fiber was stated to be of good strength and had an average length of about 5.5 feet, though it had been imperfectly prepared. From these data it was concluded that roselle fiber is somewhat inferior in chemical composition and behavior to jute fiber, since it lost more on hydrolysis and contained less cellulose.

Frenzl and Bruggencate (16) found in a study of the spinning and weaving qualities of roselle fiber from Java that it was not inferior in strength to first-class jute fiber. They also found that the color was better than that of first-class Calcutta jute, and that the flexibility was less than in jute. The spinning and weaving of roselle fiber with the methods in use for jute gave some difficulty. Cloth made from roselle yarn appeared good, but because of the lower flexibility, the cloth and yarn were not so strong as that made from jute. They concluded that sugar bags made from roselle fiber would be usable in the Dutch sugar factories, but that the fiber would not be suitable in tapestry. Lack of flexibility was the only fault that Oudot (37) and Spoon (42) found with sacks made from the fiber.

TABLE 4
COMPARISON OF ROSELLE AND JUTE FIBER

	Hibiscus Sabdariffa	*Extra fine Indian jute*
	%	%
Moisture	8.9	9.6
Ash	1.1	0.7
a hydrolysis, loss	12.3	9.1
b hydrolysis, loss	17.8	13.1
Acid purification, loss	1.5	2.0
Cellulose	73.9	77.7
Length of bast cells	0.08 to 0.16 in.	0.06 to 0.12 in.

Other Plant Parts. Howard and Howard (25), discussing the uses of roselle, stated: "Almost every part of the plant can be utilized. The stems yield a strong silky fibre known to commerce as 'Rozelle Hemp'. The fleshy calyces, which have a pleasant acid taste, and a very attractive red color are extensively used in jellies, chutnies and preserves. In the West Indies a cooling drink is also prepared from them. The seeds are useful in medicine and the leaves are employed for salads and curries".

The calyces of the edible varieties of *Hibiscus Sabdariffa* can be made into

a sauce, similar to cranberry (*Vaccinium macrocarpon* Ait.) in color and flavor, which can be used as a filler for shortcakes and pies (49). The calyces can be used in the manufacture of jelly, sirup, flavoring extracts and wine. Similar products may be made from the tender leaves and stems, and resemble the preparations made from the calyces except that the color is less brilliant. Because of the similarity in the uses and flavor of roselle products to those of cranberry products, a comparison of their analyses is of interest (49). The following of roselle were made on the calyx after the refuse, which is about 50 percent of the weight of the calyx, consisting of the seed pod and the stem end of the calyx, had been cut away:

TABLE 5

ANALYSIS OF ROSELLE CALYX AFTER SEPARATION FROM SEED POD AND STEM

Constituents	*Roselle grown in the Philippines*	*Roselle grown in Florida*	*Cranberry*
	%	%	%
Water	82.49	88.91	88.53
Solids	17.51	11.09	11.47
Ash	1.26	0.89	0.25
Marc (insoluble matter)	7.39	6.67	4.60
Acid (as malic)	3.31	2.77	2.74
Reducing sugar as invert	0.82	0.33	1.90
Sucrose	0.24	0.03	0.10
Benzoic acid	Absent	Absent	Present

Heath (20) stated that quince juice was often combined with roselle juice in jelly-making and that the roots contain saponin. Watt (44) asserted that the fleshy calyx is a valuable antiscorbutic, and is much eaten in the form of jellies, chutneys and preserves in India. The leaves have been consumed there as a salad and in native curries, and the seeds have been employed in medicine because of their demulcent, diuretic and tonic properties. Cook and Collins (8) stated that the calyces may be preserved by drying and in this condition were sometimes found in tropical markets. Leupin (30) told of a drug called "karkade" that was obtained from the red-stalked varieties, the contents of which were oxalic, malic, citric and tartaric acids.

Dunstan (14) reported the nutrient value of roselle seeds as somewhat higher than that of linseed or cottonseed cake, and said this was due to the large percentage of fat they contained. The seeds were lower, however, in albuminoids and contained little or no starch. The amount of indigestible matter or crude fiber present was particularly large, and, on account of this fact and the hard nature of the seed coat, the value of the material as a feeding stuff for cattle was considerably diminished. Dunstan remarked that the natives of northern Nigeria ground the seed into a coarse meal and used it as a food.

Georgi (17) found that *Hibiscus Sabdariffa* var. *altissima* seed contains about 17 percent of an oil which is very similar to both kapok and cotton seed oils and can doubtless be used for the same purpose as these oils.

Summary

Roselle, *Hibiscus Sabdariffa*, belongs to the family Malvaceae. It is an annual plant that is grown for its bast fibers and its edible calyces and leaves. There are several varieties, some of which are of a tall, comparatively unbranched type, suitable for fiber production, and others are of a shorter, much-branched type, cultivated, generally, for their edible calyces. Both types, on the basis of color characteristics, have been divided into three groups: plants of which the stems are red, plants of which the stems are green, and plants intermediate between the red- and green-stemmed types. Varietal names, based primarily on color differences, especially in the short, much-branched type of

plant, have been given to the two groups differing in growth habit.

Although roselle appears to be adapted to wide variations in climatic and soil conditions, a well-drained sandy loam soil with a considerable quantity of humus appears to best meet the requirements of the plant. From six to ten inches of rainfall per month for three to four months is essential for the successful production of roselle fiber. Likewise the length of the daily light period during the time when the crop is grown should be approximately 13 hours or greater in order to prevent flower bud initiation and subsequent blossoming until after the plants have reached a sufficient height to insure profitable yields of fiber. Similar environmental requirements are essential for the production of roselle fruit (calyces). The growing season should be five to six months long, accompanied by day lengths of less than 13 hours during the latter part of this period to promote blossoming and subsequent fruit production.

Planting may be done by broadcasting, seeding in rows or drilling, but the last method seems to be preferred for fiber production. The optimum planting distance is dependent upon soil fertility and related factors, but, generally speaking, for fiber production a distance of from four to eight inches between plants in rows six to twelve inches apart has been used. Planting distances for seed or fruit production are considerably increased. Weed competition during the early part of the growing season should be kept at a minimum.

Upon harvesting, the plants are either pulled up by the roots or cut off at ground level. The stalks are tied in bundles and retted in water, or the cortex may be stripped from the stalks in the field, tied in bundles and retted. Generally retting is complete in from eight to ten days. The fiber is then removed, washed and dried. The yield of dried fiber varies from 1,000 to 2,000 pounds per acre, depending upon soil, environmental conditions and other factors. Fruit yield may reach as high as 15,000 pounds per acre.

Roselle fiber may be employed in the manufacture of sacking material, ropes and cordage of all kinds, fishing nets and articles for which jute fiber is used. The enlarged fleshy calyces seem to offer an excellent substitute for cranberries and may be used as a filler for shortcakes and pies, and in the manufacture of jelly, sirup and flavoring extracts. Roselle seed contains about 17 percent of an oil which is similar to both kapok and cotton seed oils.

If roselle is to become a commercially important crop in this hemisphere, mechanical methods of planting, harvesting and fiber extraction will have to be developed. Mechanical methods now used in the production of kenaf seem adaptable.

Literature Cited

1. Anonymous. Review of experiments on fiber-producing plants. Philippine Agr. Rev. **18:** 143–149. 1925.
2. Adbur Rahman Khan, Khan Sahib. A new type of roselle hemp. Agro. Jour. India **25:** 210–212. 1930.
3. Beattie, J. H. Production of roselle. U. S. Dept. Agr., Lft. 139. 1937.
4. Bolhuis, G. G. Bloeiwaarnemingen bij *Hibiscus Sabdariffa* L. en *Hibiscus cannabinus* L. Landbouw **16:** 404–412. 1940.
5. Calvino, Mario. El sereni textil (*Hibiscus Sabdariffa*, var. *altissima*). Cuba. Estac. Expt. Agron. Informe, 1918–20, pp. 478–482. 1920.
6. Campese, Oreste. La coltura della rosella e la preparazione delle fibre. Colture Tropicali e Lavorazione dei Prodotti, v. 3, pp. 293–314. 1937.
7. Canagaratnam, V. Cultivation of roselle fibre and its possibilities (*Hibiscus Sabdariffa* var. *altissima*). Trop. Agr. (Ceylon) **73:** 229–232. 1929.
8. Cook, O. F., and Collins, G. N. Economic plants of Porto Rico. U. S. Nat. Mus., Contrib. U. S. Nat. Herb., v. 8, pt. 2, pp. 57–269. 1903–05.
9. Crane, J. C., and Acuna, J. B. Varieties of kenaf (*Hibiscus cannabinus*), a bast fiber plant, in Cuba. Bot. Gaz. **106:** 349–355. 1945.

10. ————. Kenaf—Fiber-plant rival of jute. Econ. Bot. **1**: 344–350. 1947.

11. Dekker, J. F. Java-jute en roselle. Landbouw **9**: 507–513. 1934.

12. Deshpande, R. B. Studies in Indian fibre plants. No. 5. Further studies on the inheritance of certain characters in *Hibiscus Sabdariffa* L. Indian Jour. Agr. Sci. **8**: 229–243. 1938.

13. Drury, Herber. The useful plants of India. 559 pp. 1858.

14. Dunstan, W. R. Some African food grains. (Gt. Brit.) Imp. Inst. Bul. 7: 145–154. 1909.

15. Ettling, Carl. Die Rosella-Pflanze (*Hibiscus Sabdariffa*), ihr Anbau und ihre Verwertung. Tropenpflanzer **29**: 2–23. 1926.

16. Frenzel, W., and Bruggencate, A. Ten. Spin- en weefproeven met rosellevezel ven Java. (Netherlands) Rijksvoorlichtingsdienst ten Behoeve Vezelhandel en Vezelnijverheid. Meded. 22. 1929.

17. Georgi, C. D. V. Roselle seed oil. Malayan Agr. Jour. **11**: 223–224. 1923.

18. (Great Britain) Imperial Institute. Hibiscus fibres from the Northern Territories, Gold Coast. (Gt. Brit.) Imp. Inst. Bul. 10: 51–55. 1912.

19. ————. Hibiscus fibres from India and Iraq. (Gt. Brit.) Imp. Inst. Bul. 28: 284–289. 1930.

20. Heath, E. S. Roselle (*Hibiscus Sabdariffa* L.) Pomona Col. Jour. Econ. Bot. **2**: 378–381. 1912.

21. Henning, G. E. Roselle fibre, *Hibiscus Sabdariffa* var. *altissima*. Malayan Agr. Jour. **10**: 206–208. 1922.

22. ————. Roselle fibre (*Hibiscus Sabdariffa* var. *altissima*). Trop. Agr. (Ceylon) **60**: 200–202. 1923.

23. Hermann, Paul. Horti Academici Lugduna-Batavi catalogus. 699 pp. 1687.

24. Horst, W. A. Studien uber Gambohanf. Faserforchung **4**: 61–124. 1924.

25. Howard, Albert, and Howard, G. L. C. Studies in Indian fibre plants. No. 2. On some new varieties of *Hibiscus cannabinus*, L. and *Hibiscus Sabdariffa*, L. Indian Dept. Agr., Mem. Bot. Ser. **4**: 9–36. 1911.

26. Hughes, Griffith. The natural history of Barbados. 314 pp. 1750.

27. Jones, H. A., and Rosa, J. T. Truck crop plants. Ed. 1, 538 pp. 1928.

28. Koch, L. Sur la roselle (*Hibiscus Sabdariffa altissima*). Rev. Bot. Appl. et d'Agr. Colon. **6**: 754–757. 1926.

29. ————. *Hibiscus Sabdariffa, altissima*. Trop. Agr. (Ceylon) **68**: 80–82. 1927.

30. Leupin, K. Karkade. Pharm. Acta Helvetiae **10**: 138–142. 1935.

31. L'Obel, M. de. Plantarum, sev Stirpivm historia. 671, 457–471, 15, 24. 1576.

32. McClelland, T. B. Effect of variation in day length on growth of certain plants. Puerto Rico Agr. Exp. Sta., Rep. **1924**: 10–11. 1924.

33. Mathieu, E. Roselle fibre. Fed. Malay States Agr. Bul. **8**: 231–240. 1920.

34. Medvedeva, G. B. Karyological review of 15 species of the genus *Hibiscus*. Jour. Bot. de l'URSS **21**: 533–550. 1936.

35. Mendiola, N. B. A study of Philippine bast fibers. Philippine Agr. **6**: 6–38. 1917.

36. Michotte, Felicien. Les *Hibiscus* (Ketmie). Traite Sci. et Ind. Plantes Textiles Bul., Nos. 3–6. 1928.

37. Oudot, G. Plantes à fibres. I–III. Bul. Econ. Indochine **43**: 77–91. 1940.

38. Prat, D. de. Une nouvelle plante textile coloniale: le chanvre de rosella. Rev. Int. Prod. Colon. **12**: 107–110. 1937.

39. Reyes, T. P. The effects of fertilizers added to soil on the growth of roselle plants and production of fiber. Philippine Agr. **10**: 350. 1922.

40. Royle, J. F. The fibrous plants of India. 403 pp. 1855.

41. Sloane, Sir Hans. A voyage to the islands Madera, Barbados, Nieves, S. Christophers and Jamaica, with the natural history of the herbes, trees. 2 v. 1707.

42. Spoon, W. Nieuwe beoordeelingen van Java-jute en roselle. Bergcultures **12**: 1114–1119. 1938.

43. Straits Settlements and Federated Malay States. Dept. Agr. Guide to the Experimental Station, Serdang, 1931. 141 pp. 1931.

44. Watt, Sir George. The commercial products of India. 1,189 pp. 1908.

45. Wester, P. J. Roselle: its culture and uses. U. S. Dept. Agr., Farmers' Bul. 307. 1907.

46. ————. Contributions to the history and bibliography of the roselle. Torrey Bot. Club Bul. **38**: 91–98. 1911.

47. ————. Roselle, its cultivation and uses. Philippine Agr. Rev. **5**: 123–132. 1912.

48. ————. New varieties of roselle. Philippine Agr. Rev. **7**: 266–269. 1914.

49. ————. The cultivation and uses of roselle. Philippine Agr. Rev. **13**: 89–99. 1920.

50. Youngberg, Stanton. Twenty-sixth annual report of the Bureau of Agriculture, Philippine Islands. 1926.

51. ————. Resumé of the annual report of the Bureau of Agriculture for the year ending Dec. 31, 1928. Philippine Agr. Rev. **22**: 89–192. 1929.

Utilization Abstracts

Essential Oils. When Old-World sources of essential oils, on which consumers of those oils in the U. S. A. have been to a very large extent dependent, were cut off by World War II, numerous attempts were made in North, Central and South America to produce the same oils or others that might take their places. Many important economic and technical considerations, discussed in this article, were overlooked by would-be producers in seeking these replacements.

In the U. S. A., for instance, because of high labor costs, essential oils can be successfully produced commercially only as by-products, for example, citrus oils, or only when the plants can be cultivated and harvested by machinery, as in the production of the peppermint and dill oils of the West. For the same labor cost reasons, attempts to produce eucalyptus oils on a large scale in California had to be forsaken. Commercial use of wild plant material in the U. S. A. is likewise limited. Native wintergreen oil [*Gaultheria procumbens*] and sweet birch oil [*Betula lenta*] have attained some importance, and among the newer oils from wild plants is that of wild carrot, or Queen Ann's lace [*Daucus Carota*]. The American product is distilled from the whole herb, whereas the French carrot oil is obtained only from the seed.

In California an essential oil has been produced on a small scale from the mountain laurel, or California bay tree (*Umbellularia californica*), which is not to be confused with commercial laurel-leaf oil distilled from *Laurus nobilis*. The California oil has an annual consumption in the U. S. A. of perhaps only 100 pounds, and utilization of greater quantities by conversion of the umbellulone in the oil through hydrogenation into thymol must compete with already established large scale production of thymol from parcymene, a very cheap starting material.

Ocimum oils and the oil from the wild American sage, *Artemisia tridentata*, contain large amounts of natural camphor, "but the cost of the camphor separated from the oils is higher than that of the synthetic product manufactured from pinene obtained from turpentine".

Vetiver oil, distilled from the roots of very old wild plants [*Vetiveria zizanioides*] in Haiti, was accepted in the trade only when the war cut off the supply of better oil from the roots of highly cultivated plants, usually not more than two years old, in Réunion and Java. The American oil has continued to be in demand since it was once accepted, and production of it in Haiti is increasing.

Other attempts to produce essential oils that have been commercially unsuccessful because of economic and technological difficulties, include patchouly [*Pogostemon Cablin*] in the Western Hemisphere, sweet basil oil (*Ocimum Basilicum*) in Haiti, lavender oil [*Lavandula officinalis*] in the State of Washington, and ylang ylang [*Canangia odorata*] in Honduras.

Despite the foregoing and other difficulties associated with the development of new sources of essential oils, the following new ones for the Western Hemisphere show promise of commercial success:

I. South American Oils

OIL OF *OCOTEA PRETIOSA* or OIL OF *OCOTEA CYMBARUM*:—Formerly known as "Brazilian sassafras oil". About 200 tons produced annually in Brazil. Contains about 90% safrole, an important isolate and intermediate for isosafrole and heliotropin, both important perfume and flavoring ingredients. "The unavailability, due to the war, of the usual source of safrole (namely, Formosan, Japanese and Chinese camphor oil fractions) caused the immediate acceptance of this Brazilian product".

OIL OF *MENTHA ARVENSIS*:—Brazilian production has decreased from about 2,000 tons in 1945 to about 150 tons in 1947. "Substantial quantities of this oil have been produced in Brazil, primarily for the isolation of natural *l*-menthol of U. S. P. quality. Neither the oil nor the dementholized oil can be used as a pharmaceutical in the United States because the official U. S. P. oil must be distilled from *Mentha piperita*. Importation is permitted only under affidavit", and its use must be other than as a pharmaceutical.

OIL OF SWEET ORANGE [*Citrus*

sinensis]:—Brazilian production has decreased from about 120 tons in 1926 to about 40 tons in 1947, but "has eased the situation caused by the temporary disappearance of sweet orange oil from French Guinea".

OIL OF MANDARIN [*Citrus nobilis* var. *deliciosa*]:—About 1,000 kilograms produced annually in Brazil. The oil was accepted in the trade when Italian imports were suspended. It differs from the Italian product in being machine-pressed instead of hand-pressed and in being deep green instead of yellow.

OIL OF *EUCALYPTUS* — Cineole type [*Eucalyptus globulus*]: — Potential production is very great, since many hundreds of thousands of trees have been planted in South America, but "competition with the long established Australian oils will prove difficult".

OIL OF *EUCALYPTUS CITRIODORA*: —Ten to 12 tons produced annually in Brazil. "This oil contains the aldehyde, citronellal, as its main constituent. Large quantities of citronellal are used in this country for conversion into hydroxy-citronellal and into synthetic menthol."

OIL OF CABREUVA [*Myrocarpus frondosus*]. Production figures are unavailable, but in 1946 more than 700 kg. were exported from Santos alone. "The oil has excellent fixative properties, and has the very soft odor characteristic of a sesquiterpene alcohol. Whether or not it will win a permanent place in commerce is still uncertain and will depend primarily upon the price of the oil."

II. Central American Oils

OIL OF CITRONELLA [*Cymbopogon Nardus*]:—About 200 tons produced annually at present in Guatemala, Honduras and Haiti where this plant has been successfully introduced. The oil is well established in commerce today in competition with that from Java.

OIL OF LEMONGRASS [*Cymbopogon citratus*]:—About 30 tons produced annually in Guatemala and Honduras in competition with oil from the East Indies. "This oil is an important source for the aldehyde, citral, useful in flavors and also as an intermediate for the production of the ionones".

OIL OF *EUCALYPTUS STAIGERIANA*.—A few hundred pounds produced annually. "In addition to citral, the oil appears to contain geranyl acetate and geraniol, resulting in a very pleasant fruity, lemon-like odor and flavor."

OIL OF CORIANDER [*Coriandrum sativum*]:—Very small quantities produced in Guatemala, and commercial acceptance still uncertain.

III. West Indian Oils

OIL OF NEROLI:—Production in Haiti very variable, but up to 1,000 pounds could be produced annually if necessary. "It is distilled from the flowers of a variety of orange (probably the bitter-sweet) different from that cultivated in Europe. The flowers are collected from semiwild and wild-growing trees which have escaped from cultivation long ago. Besides, the plant material is not carefully selected and is often admixed with flowers from the shaddock, parent plant of the American grapefruit. The odor is quite different from the oil neroli bigarade produced in France".

OIL OF PETITGRAIN:—[From the leaves and twigs of both bitter and sweet oranges]. About ten tons produced annually in Haiti.

OIL OF VETIVER:—About ten tons produced annually in Haiti. "The Haitian oil is distilled from the very old roots of semi-wild growing plants [*Vetiveria zizanioides*]. Although the odor differs somewhat from the Java and Réunion types, the oil has been accepted by the trade".

OIL OF LEMONGRASS:—About ten tons produced annually.

IV. North American Oils

OIL OF TANGERINE:—Up to ten tons could be produced annually in Florida if the demand warranted. "This oil is obtained as a by-product from the canning of tangerine juice. Substantial quantities are potentially available. The oil cannot replace any of the other citrus oils. The Florida tangerine oil apparently contains no methyl ester of N-methyl anthranilic acid, or if this ester is present, it occurs in traces only. Hence the oil is very different from mandarin oil. The trade has not generally accepted this oil as yet. Recent samples extracted in new types

of juice and peel presses had a much improved odor and flavor, approaching the true character of the tangerine peel".

OIL OF LEMONGRASS:—No production in Florida at present. "Lemongrass was planted as a supplementary crop by a sugar cane grower. After distillation of the oil, the exhausted plant material was mixed with molasses residues and used as a cattle food. Production of this oil has recently been discontinued for economic reasons".

OIL OF CEDARWOOD:—Large potential production in Texas. "This oil is distilled from *Juniperus mexicana* Schiede, and not from the *Juniperus virginiana* L., the source of the cedarwood oils of the South. The two oils are quite similar in composition, but the new Texas product appears to have a somewhat harsher odor. Analytically, the main difference observed is the much greater laevorotation of the Texas product. Large quantities of oil can be made available if the demand should warrant it". *(E. S. Guenther & E. E. Langenau, Proc. Sci. Sect., The Toilet Goods Assoc., Nov. 8, Dec. 1947).*

Cannery Residues. Cannery residue wastes in the United States, amounting to thousands of tons annually, have been found to contain "sugars, oils, pectins, waxes, proteins, tannins, acids, enzymes and a variety of other organic compounds". These are contained in the waste pits of apricots, peaches, prunes, olives and cherries; the shells of walnuts, filberts and almonds; seeds of apples, tomatoes, grapes, citrus fruits and melons; leafy and butt trimmings; fruit skins, cores and trimmings; peels and rinds of melon and citrus fruits; pomace from juice factories and wineries; stems, pods, hulls, cobs, husks and vines.

If the technological and economic problems associated with recovering these materials can be solved, there are great possibilities for new byproducts industries. Investigations toward this end have been pursued by many Federal, State and private agencies. The results of these studies so far have shown, among other things, that:

a) Leafy wastes, more so than stem wastes, from beets, spinach, broccoli, carrots, cabbage, cauliflower, kale, lima beans, peas, rutabagas, tomatoes and turnips contain a rich supply of carotene, riboflavin and protein.

b) Broccoli meal is nutritionally better than commercially produced alfalfa meal for poultry feed supplement, and meal from turnip and carrot tops is as good as alfalfa meal.

c) Lima bean wastes, pea vines, pea pods and asparagus butts may be found to yield valuable meal, either alone or in mixture with alfalfa.

d) Asparagus-waste juice is of use in culturing *Bacillus subtilis* to produce the antibiotic subtilin.

e) "Corncobs, oat hulls, cottonseed hulls, flax shives, peanut shells, and rice husks are being utilized by the duPont Company to manufacture a key intermediate product for nylon. A new million dollar plant at Niagara Falls, New York, was built by duPont to study further this problem of utilization".

f) "The Western Regional Research Laboratory has recently developed a new protective coating for meat and other products, made from citrus peel, apple pomace and vegetable waste products. A soluble pectinate, treated chemically, forms a gel or film to provide a very strong protective film. This film will dissolve when the product it covers is boiled and it may be left on and eaten as it is tender and edible".

g) Fermentation of pear waste—45% of the raw product—might yield alcohol, vitamin-B, glycerol, acetone, butyl alcohol, amyl alcohol, manite, pyruvic acid, yeast, syrup and vinegar. In 1947 there were 96,000 tons of waste from pears.

h) Apple peels and cores have been used for syrup; a syrup from concentrated apple juice has been used by one cigarette manufacturer to replace glycerin; and apple waste is the source of manufactured pectin and wax.

i) "Three products—ursolic acid, cranberry wax and oil—have been produced on a limited scale to utilize cranberry wastes. The acid might well be an excellent ingredient for cosmetics and has already proven to be a good water-in-oil emulsifying agent. It has been said that a cream prepared from the wax and ursolic acid is an excellent medicine for burns".

j) Apricot, peach and cherry pits yield a refined sweet oil suitable for cooking, pharmaceuticals, cosmetics and packing sardines. "Bitter almond oil, recovered from sweet oil press cake, may be used as a medicinal without further treatment. Apricot kernels provide the source of practically all the macaroon paste used by bakers. Ground apricot and peach pits may be used as dynamite base, wood flour for plastics or for the preparation of absorbent charcoals. Acetic acid, acetone and charcoal are products of whole peach pits which have been dried". (*E. H. Wiegand, Chemurgic Digest* 7(1): 9. 1948).

Peanuts in Africa. As one measure of meeting the world-wide shortage in fats and oils, the British Government, in December, 1946, adopted a "Report of a Mission to Investigate the Practicability of the Mass Production of Groundnuts in East and Central Africa". This report recommended the establishment of 107 mechanized units, each of 30,000 acres extent and all totaling nearly 3¼ million acres (over 5,000 square miles), 80 of the units for Tanganyika Territory, 17 for Northern Rhodesia and 10 for Kenya. This ambitious project, involving enormous expenditures and problems in introducing mechanized farming to unoccupied agricultural land, was regarded as capable of producing 50,000 tons of groundnuts, or peanuts, in 1948, and a maximum of 400,000 tons by 1951. Combatting malaria and sleeping sickness is only one of the problems involved, and eventually, it is estimated, 100,000 people will be engaged in the undertaking. The first crop was gathered in May, 1948, from 7,500 acres planted in December, 1947.

"To the average consumer of peanut butter, salted peanuts, or peanut candy (the three widest uses in the United States) the food has no great significance beyond its agreeable taste. Few realize, for instance, that peanuts are one of the six basic food crops in the United States, that peanut production in the United States is worth three times that of rye, or that as a cash crop, in the State of Georgia, peanuts are a close runner-up to cotton.

"Nobody was much interested in cultivating peanuts in the United States until the first years of this century when the arrival of the boll weevil from Mexico compelled Southern farmers to turn some of their attention from cotton to peanuts. In 1909, around 550,000 acres of peanuts were picked and threshed. By the middle years of World War II this figure had increased seven times.

"In 1938 the United States was still far from being a leading exporter of peanuts. India, producer of nearly three-quarters of the quantity that entered into world trade, led the list. Senegal, China, Japan and Nigeria furnished the next largest amounts. The biggest importers were France, Britain, Germany and the Netherlands, countries which processed the nuts and then (except for Germany) were the largest exporters of peanut oil.

"The war brought many changes in production and export patterns. India, the leading pre-war exporter, sent out none in 1946. British East and West Africa (including Nigeria) jumpted into first place, followed by French West and Equatorial Africa (including Senegal). China and Japan dropped right out of the picture, leaving the United States in third place, although her exports were not high. The continent of Africa is today supplying most of the word exports of peanuts and peanut oil". (*Not Just Peanuts. Publ. by British Information Services, 1948*).